SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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AUGUST, 1956—VOL. 28, No. 8

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OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

CALIFORNIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

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A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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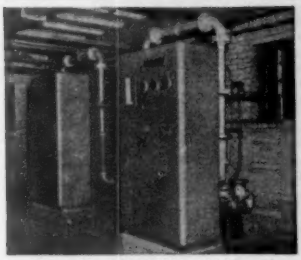

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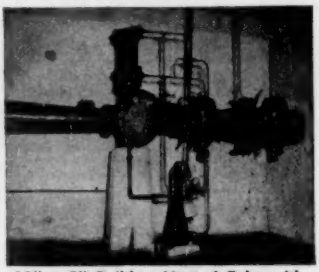

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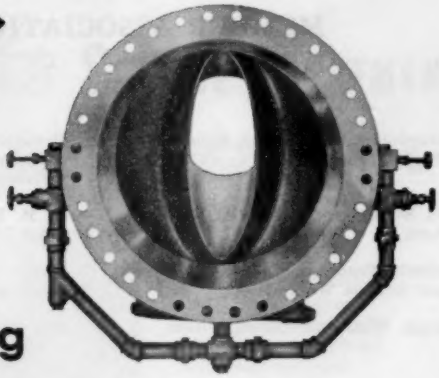

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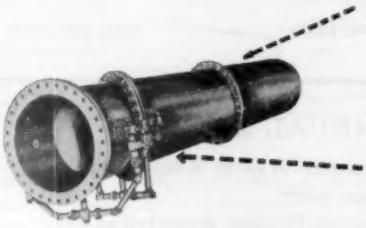

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Association	*Place*	*Time*
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Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Hotel Patten Chattanooga, Tenn.	Sept. 17–19, 1956
Georgia Water and Sewage Assn.	Hightower Textile Bldg. Georgia Inst. of Technology, Atlanta, Ga.	Sept. 19–21, 1956
South Dakota Water and Sewage Works Conference	Sherman Hotel Aberdeen, S. D.	Sept. 19–21, 1956
Missouri Water and Sewerage Conference	Hotel Governor Jefferson City, Mo.	Sept. 30–Oct. 2, 1956
Abwassertechnische Vereinigung	Dusseldorf, Germany	Oct. 3–5, 1956
North Dakota Water and Sewage Works Conference	Lewis and Clark Hotel Mandan, N. D.	Oct. 3–5, 1956
Pacific Northwest Sewage and Industrial Wastes Assn.	Boise, Idaho	Oct. 4–6, 1956

TWENTY-NINTH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
California Sewage and Industrial Wastes Association
Statler Hotel, Los Angeles, California
October 8–11, 1956

Canadian Institute on Sewage and Sanitation	Prince Edward Hotel Windsor, Ontario	Oct. 29–31, 1956
West Virginia Sewage and Industrial Wastes Assn.	West Virginian Hotel Bluefield, W. Va.	Oct. 31–Nov. 2, 1956
Nebraska Sewage and Industrial Wastes Assn.	Castle Hotel Omaha, Neb.	Nov. 1–2, 1956
New England Sewage and Industrial Wastes Assn.	Hotel Weldon Greenfield, Mass.	Nov. 8, 1956
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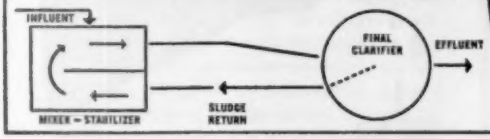

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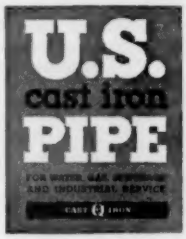

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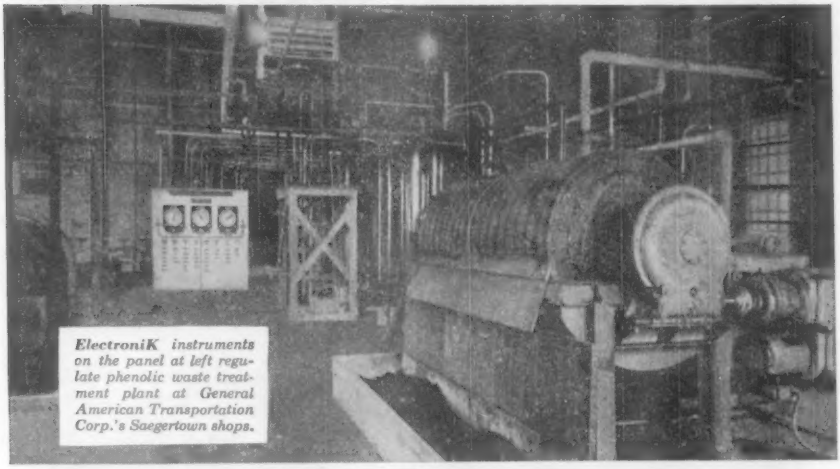

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from this to this

Glass graduate at left shows waste as it flows into settling tank at chemical plant. Mound of sludge filter cake in center represents solids taken from liquid (right) before discharge into sewerage system.

LINK-BELT Circuline Collector concentrates sludge fast in treating corrosive waste at Ohio chemical plant

In Cincinnati, surcharges are levied on industrial wastes that exceed maximum legal strength when discharged to city sewers. At the St. Bernard, Ohio plant of Toms River-Cincinnati Chemical Corporation, Cincinnati Division, corrosive and abrasive acid wastes make treatment prior to discharge to the city sewerage system the most economical disposal method.

As in municipal water and sewage plants and industries throughout the country, Link-Belt had a hand in the solution. A Circuline Collector in the settling tank gathers settled sludge so gently that minimum agitation and maximum concentration occurs. This results in high tank efficiency in removing solids and minimum costs to dewater the sludge. It is meaningful that in seeking maximum efficiency and maximum sludge density, Link-Belt equipment was recommended by the consultants, R. L. Woolpert Co. of Dayton.

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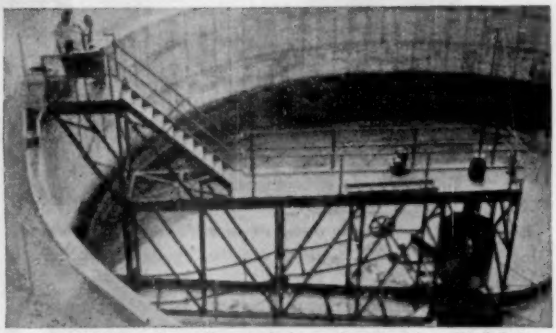

This 200,000-gal. settling tank is equipped with a Link-Belt Circuline Collector using Link-Belt Promal chain. Power is supplied through a Link-Belt worm gear and roller chain drive.

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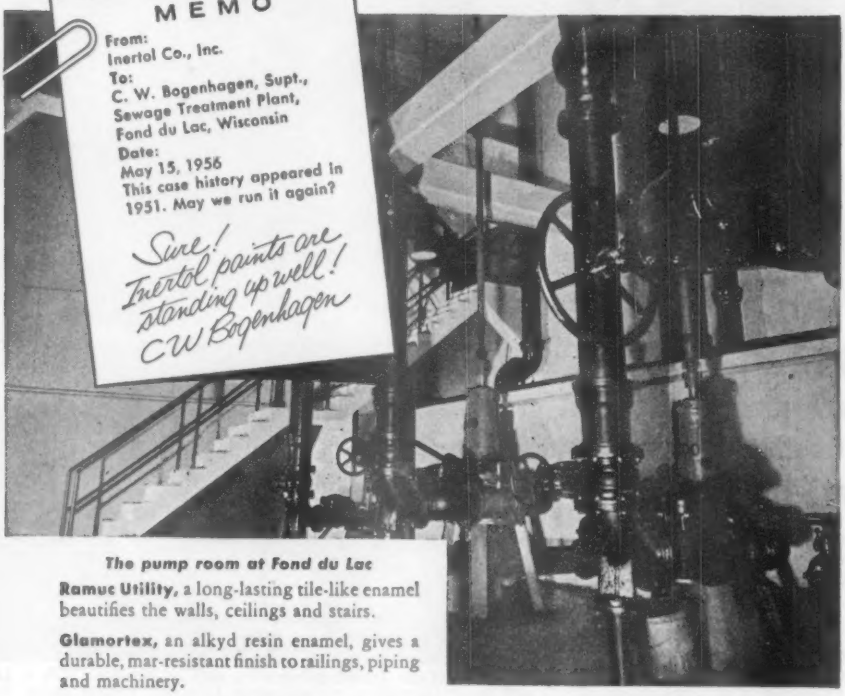

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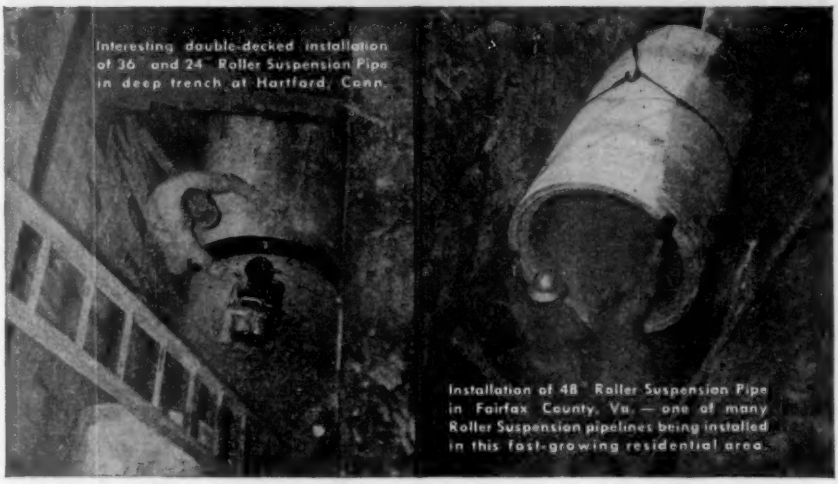

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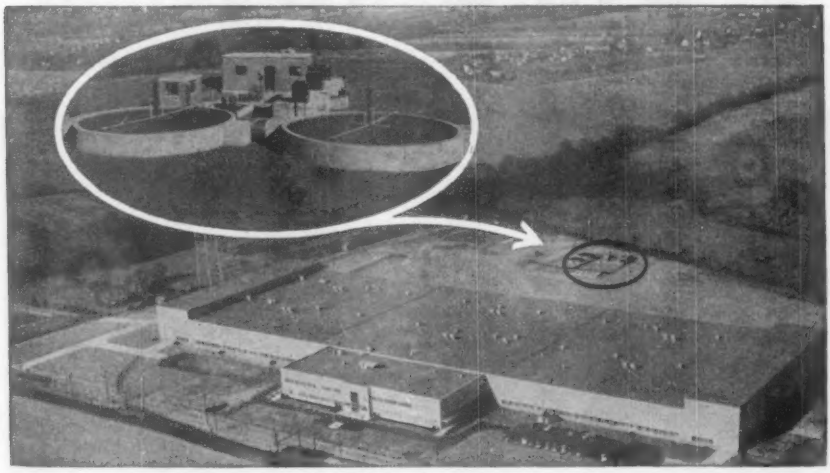
Link-Belt sewage treatment plant (inset) with PFT Rotary Distributors on 25' filter beds



Link-Belt chooses PFT Rotary Distributors for its own sewage treatment plant

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Design of plant by / Link-Belt Company Engineering Dept.

Spreader Jets for the arms of PFT Rotary Distributor. Note various positions of the hinged deflectors which raise or lower to accommodate desired flow.

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 28 | August, 1956 | Number 8

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There's a D-O UNIT for Practically Every Step in Every Sewage Treatment Flowsheet

Aerial view of the El Paso plant with the two Monorake units shown at top right. Consulting Engineers: Ashley G. Classen & Associates, El Paso, Texas

EL PASO TEXAS

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Sewage Works

TWO-STAGE TRICKLING FILTER PERFORMANCE

By J. H. Sorrels and P. J. A. Zeller

Research Engineer and Assistant Research Engineer, respectively, Texas Engineering Experiment Station, College Station, Tex.

The advantages of double or series filtration of settled sewage have been observed by several investigators. Intermedite sedimentation between filters is claimed by some to be essential, although others have obtained good results without such settling between the filters. In many cases recirculation of final effluent was employed with good results. So-called "roughing" filters, filters receiving excessively high B.O.D. loadings, have been employed as relief measures for subsequent treatment processes.

Goldthorpe and Nixon (1), using a 7-ft. deep primary filter and a 6-ft. deep secondary filter with intermediate sedimentation and an over-all loading of 0.367 lb. of 5-day B.O.D. per cubic yard, obtained an efficiency of 87.9 per cent with an effluent having 21 p.p.m. B.O.D. Dekema and Krige (2) compared two-stage and single-stage filtration. Using enclosed filters 12 to 14 ft. deep, and with forced ventilation and intermediate sedimentation, they obtained an estimated 30 per cent improvement over single-stage filtration. They observed that the sludge removed from the intermediate sedimentation tank was "black with a bad odor" and concluded that this sludge required further treatment. They also concluded that additional sludge digestion capacity would be needed with series filtration. In addition, they reversed the flow through the filters periodically with an estimated 50 per cent improvement.

Moore *et al.* (3) employed shallow (3-ft. deep) filters with recirculation but without intermediate sedimentation. A better plant efficiency was achieved with series operation, with 88.8 per cent B.O.D. removal, than with parallel operation, with 81.8 per cent B.O.D. removal. The average B.O.D. in the plant effluent with series operation was 24 p.p.m., compared with 31 p.p.m. during parallel operation.

Hagerich (4) used a "roughing" filter loaded at 2 lb. of B.O.D. per cubic yard to relieve an overloaded activated sludge plant and obtained a B.O.D. removal of 58.7 per cent of the applied load. Solids removal by the filter was 36.8 per cent.

Sewage treatment plants frequently reach designed capacity within a few years after completion and the need for increased facilities becomes acute. In a large number of plants this need is first noticed or most pronounced in filter performance. Because regulatory agencies require certain limitations with respect to filter loadings, the filter capacity should be increased as sewage flow increases.

If series filtration without intermediate sedimentation can be employed to produce a better effluent, a considerable saving in money can be realized by installing a secondary filter without an intermediate sedimentation tank. It was therefore the purpose of these investigations (a) to determine what degree of purification is accomplished by a trickling filter at excessive load-

ings without recirculation and (b) to determine the degree of purification afforded by filters in series without intermediate sedimentaion.

Experimentation

The sewage plant serving the A. & M. College of Texas is of the trickling filter, separate sludge digestion type. The four experimental filters described in a former article (5) were dosed with settled sewage by means of orifices in a constant-head tank. The effluent from each primary filter passed directly to a corresponding secondary filter without intermediate sedimentation. Each secondary filter was 4 ft. square, 3 ft. deep, and was provided with a motor-driven spinner to assure good distribution. The effluents from the secondary filters drop into a common channel, so that each secondary effluent can be sampled individually. Operation of all filters was continuous.

For a test run, samples of influent and effluent were taken hourly from 8 AM to 5 PM; composite samples were stored in a refrigerator. Time of flow of a measured sample was recorded hourly. As required, the orifices in the constant-head tank were adjusted to maintain the flow at the desired constant rate.

Composite samples, except settled sewage, were settled in an Imhoff cone for 45 min., and the amount of settleable solids recorded. About one-half liter of clarified liquor was carefully siphoned off and analyzed for pH, B.O.D., suspended and volatile solids, ammonia, nitrites, and nitrates. All analyses were made according to "Standard Methods" (6).

The dosage rates of the primary filters were 1,000, 2,000, 3,000 and 4,000 lb. of 5-day B.O.D. per acre foot per day (p.a.f.d.). The dosage rates of the secondary filters, being that portion of the B.O.D. which was not removed by the primary filters, were not subject to close control and showed rather wide fluctuations, but averaged 700, 1,700, 3,200, and 5,600 p.a.f.d., respectively. The corresponding hydraulic rates of application were, respectively: 4.46, 8.92, 13.38, and 17.83 million gallons per acre per day (m.g.a.d.) for both primary and secondary filters.

The experiments covered two years to compensate for seasonal variations.

Results

The results of the tests are shown in Tables I, II and III, and in Figures 1 to 7.

Consider first the primary filters, heavily loaded without recirculation. The loading rates are in excess of the rates usually used in design or recommended by regulatory agencies in the Southwest. It appears at once that as the loading increased, the amount of B.O.D. removed by the filter increased, but the percentage removal decreased. Stated in another way, the quality of the effluent deteriorated with increased loading. The same trend was shown by suspended solids removal. The amount of ammonia nitrogen applied to the filters was reduced very little. Even this small reduction decreased as the loading increased. A small amount appeared as nitrite nitrogen. The amount of nitrate nitrogen produced by the filters was negligible.

In the case of the secondary filters, the results were quite different. Since the secondary filters received the effluent of the primary filters directly without intermediate sedimentation, the B.O.D. loading increased at a more rapid rate, practically doubling from filter to filter. Thus, the loadings of the first two secondary filters are lower than their respective primary filters, whereas the second two show higher loadings. Per cent B.O.D. removal was higher than in the corresponding primary. The greatest difference between primary and secondary filters, however, is shown by the oxidation of nitrogen. Up to a loading of 3,100 p.a.f.d. B.O.D., substantial amounts of nitrate nitrogen

were formed, with a corresponding decrease in ammonia nitrogen. At 5,600 p.a.f.d. no nitrates were formed. In all filters, small amounts of nitrites were formed, even at the highest loading.

Suspended solids removals follow the same general trend as B.O.D. removals. As the loading increased, the absolute removal of solids increased. The quality of the effluent gradually declined.

Combinations of primary and secondary filters present still another picture. As the B.O.D. loading increased, the absolute removal increased up to a loading of 2,000 p.a.f.d. but decreased at 2,600 p.a.f.d. Percentage removal decreased and quality of effluent also deteriorated, but at a lower rate. Suspended solids and volatile suspended solids in the effluent increased as loading increased. Nitrate formation decreased steadily as loading increased. Up to 1,300 p.a.f.d. the effluent could be called well-nitrified. At 2,600 p.a.f.d. no nitrates were formed.

Discussion

Actually, the four primary filters operated in these studies were roughing filters, since they were loaded heavily without recirculation. From Figure 1 it can be seen that, in general, as the B.O.D. loading on the filters increased both the amount of B.O.D. removed by the filter and the amount of B.O.D. discharged by the filter increased. In other words, the percentage removal by the filters decreased from 63.6 per cent to 28.7 per cent as loading increased. But from 1,000 p.a.f.d. to 3,900 p.a.f.d. these rates of change were not uniform. Filter No. 4 actually removed considerably less B.O.D. at a given loading than did filter No. 3 at the same loading. Similarly, at a given loading filter No. 3 removed slightly less B.O.D. than filter No. 2 at that same loading.

It would appear, therefore, that loading alone is not the whole story. Some other factors are apparently involved. One such factor might be the hydraulic

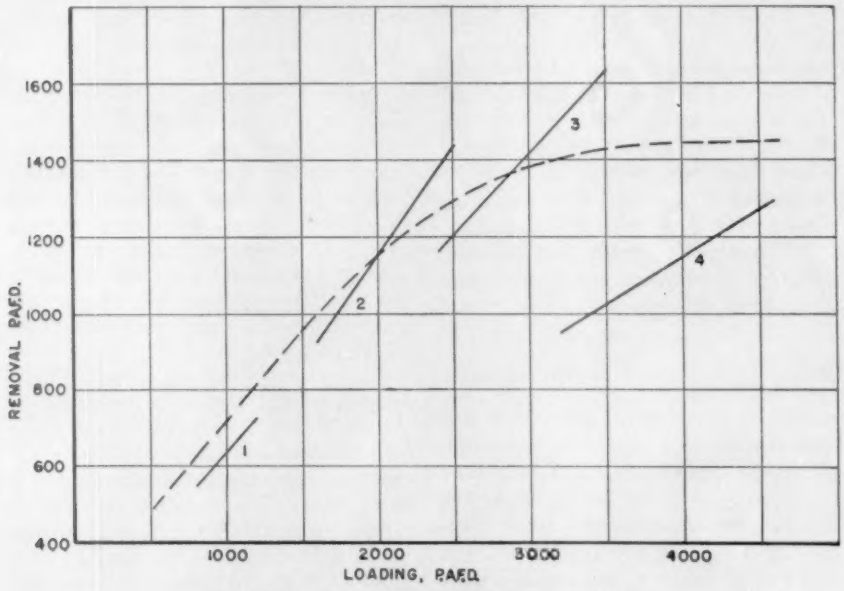

FIGURE 1.—B.O.D. removal in primary filters.

rate of application. In every case, the filter with the higher hydraulic rate shows the lower removal. This substantiates previous studies (7) showing the adverse effect of hydraulic rate on filter performance. Further, the sharp drop in removals between filters Nos. 3 and 4 suggests that there may be a limit to the removal secured by a filter, regardless of the loading. What this limit is was not demonstrated by the present studies. It would seem to be beyond a B.O.D. loading of 5,000 p.a.f.d. or 3 lb. per cubic yard per day.

The equations for B.O.D. removal by the filters, and the limits between which they apply, are as follows (the units used are pounds per acre-foot per day):

B.O.D. Removal Equations

Equation[1]	Limits (p.a.f.d.)	Hydraulic Rate (m.g.a.d.)
$R = 0.43L + 203$	800–1,200	4.5
$R = 0.58L - 4$	1,500–2,500	8.9
$R = 0.43L + 124$	2,400–3,500	13.4
$R = 0.24L + 169$	3,200–4,600	17.8

[1] R = B.O.D. removal; L = B.O.D. loading.

The corresponding hydraulic rates are also shown. In case of a choice of loadings the equation with the closer hydraulic rate would be preferable. These equations would be useful in computing filter design, or in comparing filter performance with other plants.

A hyperbolic curve for all four primary filters has been developed. It is shown by broken curve in Figure 1. The equation for this curve is $R = \frac{L}{0.000468L + 0.84}$. This equation is slightly more complicated, and neglects the effect of hydraulic rate of application. It was felt that including the hydraulic rate would make the equation too cumbersome. Up to loadings of 4,000 p.a.f.d. (or 2.5 lb. per cubic yard per day) computed values were within 5 per cent of observed values. Extrapolation beyond this limit must be used with caution.

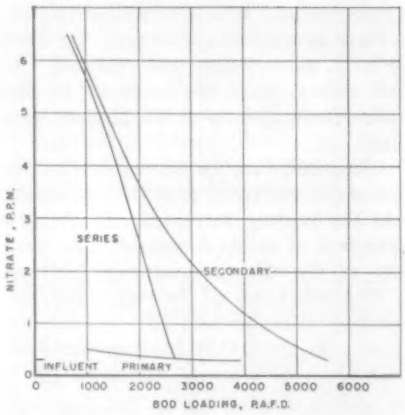

FIGURE 2.—Nitrate production in filters.

Figure 2 presents the formation of nitrates by the filters. According to theory, oxidation of nitrogen should lag behind that of carbon. If the reasoning is correct, a filter which cannot handle the carbon load should be even less able to handle the nitrogen load. Such is the case. Very little reduction in ammonia took place; and nitrate and nitrite formations were negligible (Table I).

Another function of the trickling filter is the removal of solids. Performance curves of the primary filters are shown in Figure 3. As the solids loading on the filters increases, removal of solids increases, but at a decreasing rate. In other words, as the solids loading increased from 800 to 3,200 p.a.f.d. the quality of the effluent deteriorated at an increasing rate from 47 to 76 p.p.m.

In general, the secondary filters showed similar trends to the primary. As the B.O.D. loading increased, absolute removal increased, while percentage removal decreased slowly, as shown in Figure 4. The relation between loading and removal is nearly straight-line up to a loading of 4,000 p.a.f.d. Beyond 4,000 p.a.f.d., removal drops rapidly. The percentage removal of sus-

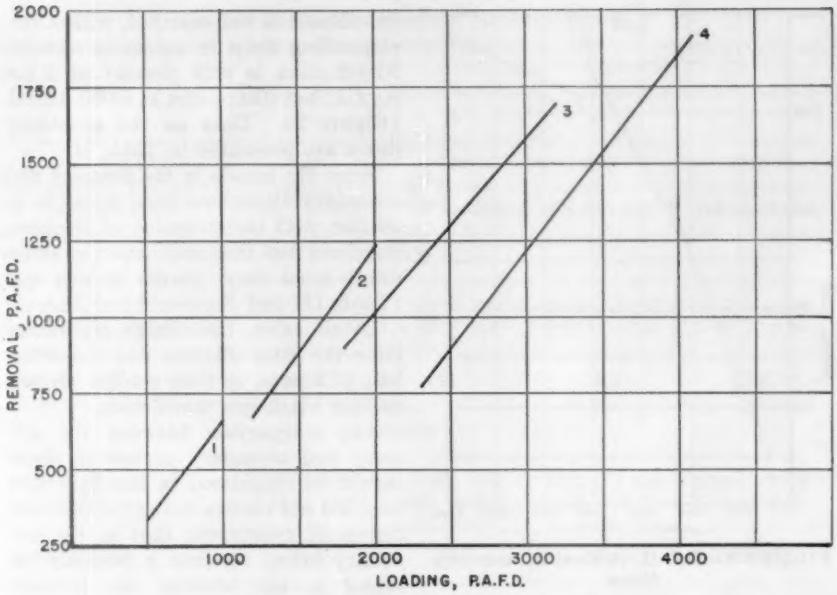

FIGURE 3.—Solids removal in primary filters.

TABLE I.—Average Results of Primary Filters

Item	Filter			
	1	2	3	4
Flow (m.g.a.d.)	4.46	8.92	13.38	17.84
B.O.D.				
Influent (p.a.f.d.)	1,000	1,994	3,015	3,935
Influent (lb./cu. yd.)	0.62	1.24	1.87	2.44
Effluent (p.p.m.)	59	69	86	116
Removal (p.a.f.d.)	636	1,149	1,426	1,130
Removal (%)	63.6	57.6	47.3	28.7
Solids				
Influent (p.a.f.d.)	814	1,627	2,454	3,207
Influent (lb./cu. yd.)	0.51	1.01	1.52	1.99
Removal (p.a.f.d.)	523	973	1,268	1,348
Removal (%)	64.3	59.8	51.7	42.0
Nitrogen				
	Influent	1	2	3	4
Ammonia (p.p.m.)	26.2	23.7	24.0	24.3	26.0
Nitrite (p.p.m.)	0.0	0.6	0.3	0.1	0.0
Nitrate (p.p.m.)	0.3	0.5	0.4	0.3	0.3

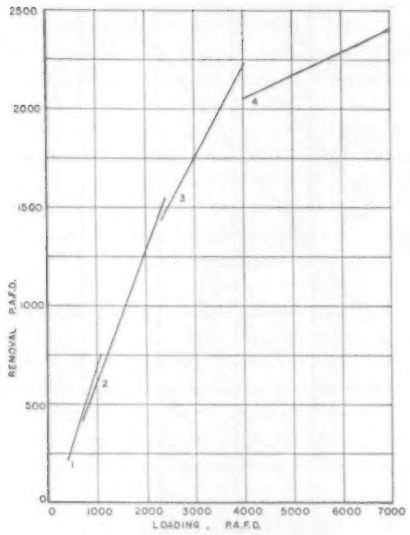

FIGURE 4.—B.O.D. removal in secondary filters.

pended solids decreases slowly up to a loading of 1,700 p.a.f.d., then drops erratically (Figure 5). As regards the oxidation of nitrogen, the secondary filters show much better results. Up to a B.O.D. loading of 1,700 p.a.f.d., the effluent is well nitrified, with a corresponding drop in ammonia content. Nitrification is still present at 3,100 p.a.f.d., but disappears at 5,000 p.a.f.d. (Figure 2). Data on the secondary filters are presented in Table II.

Since the trends in the primary and secondary filters have been shown to be similar, with the exception of nitrogen, it follows that the combination or series filters must show similar trends also (Table III and Figures 6 and 7).

In all cases, the sludge separating from the filter effluents was characteristic of humus, or filter sludge. It was neither black nor malodorous.

Any comparison between the primary and secondary groups of filters should be considered in the light that they did not receive sewage of the same degree of treatment; that is, the secondary group received a partially oxidized sewage whereas the primary group received settled sewage.

In Table IV are presented data showing the absolute quantities of B.O.D. and suspended solids applied to and removed by the filters. It is interesting to note that as the loading on the filters increases the ratio of the B.O.D.

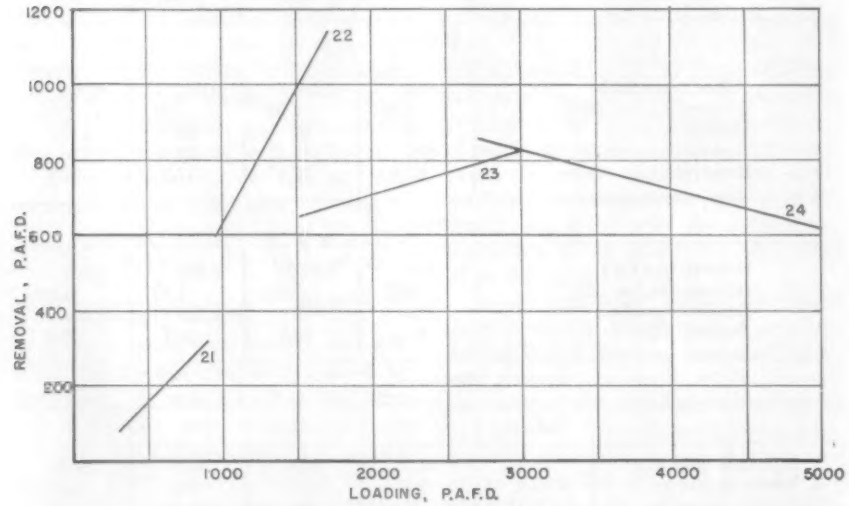

FIGURE 5.—Solids removal in secondary filters.

TABLE II.—Average Results of Secondary Filters

Item	Filter							
	21		22		23		24	
Flow (m.g.a.d.)	4.46		8.92		13.38		17.83	
Sampling point	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.
B.O.D.								
Influent (p.a.f.d.)	727	264	1,691	614	3,176	1,316	5,610	3,358
Influent (lb. per cu. yd.)	0.45	0.29	1.05	0.67	1.97	1.15	3.48	1.40
Removal (%)	63.7		63.7		58.6		40.1	
Solids								
Influent (p.a.f.d.)	582	387	1,308	851	2,373	1,698	3,769	2,974
Influent (lb. per cu. yd.)	0.36	0.12	0.81	0.28	1.47	0.42	2.34	0.49
Removal (%)	33.5		34.9		28.4		21.1	
Nitrogen								
Ammonia (p.p.m.)	23.7	17.5	24.0	18.8	24.3	21.7	26.0	24.8
Nitrite (p.p.m.)	0.6	0.6	0.3	0.6	0.1	0.3	0.0	0.1
Nitrate (p.p.m.)	0.5	6.5	0.4	4.9	0.3	1.7	0.3	0.3

removal by the secondary filters to the removal by the primary filters approaches unity. Since the secondary units have a volume of one-half that of the primary units, this means that the rate of removal in pounds per cubic yard approaches twice that of the primary. This increase is especially apparent at loadings on the primary filters greater than 3,000 p.a.f.d. In contrast to the increased ratio of B.O.D. removal, the ratio of removal of suspended solids increases but slightly as the suspended solids loading increases. These ratios are shown in Figure 8.

A trickling filter acts as a flocculating agent as well as an oxidizing agent. The organisms on the filter media adsorb the organic matter, ingest it, and partly oxidize it. As the B.O.D. loading increases, these organisms become less capable of oxidizing the organic matter in the time available. The action then becomes primarily one of flocculation and the removal of organic matter from solution. This is substantiated, in part, by the data in Table IV. The ratios of B.O.D. removal to solids removal in the primary filters are seen to be fairly constant and are: 1.22, 1.18, 1.12, and 0.84, respectively. These ratios show that with increased load a greater proportion of solids is removed compared to B.O.D. removed. The oxidation effect of the filters is illustrated by the same ratios in the secondary units. These range from 2.32 to 2.82 and indicate that considerably more B.O.D. than solids is removed.

The oxidizing effect of the secondary filters is further evidenced by the increased nitrification occurring in these units (Figure 2).

The ratio of adsorption to oxidation may possibly account for the effect of

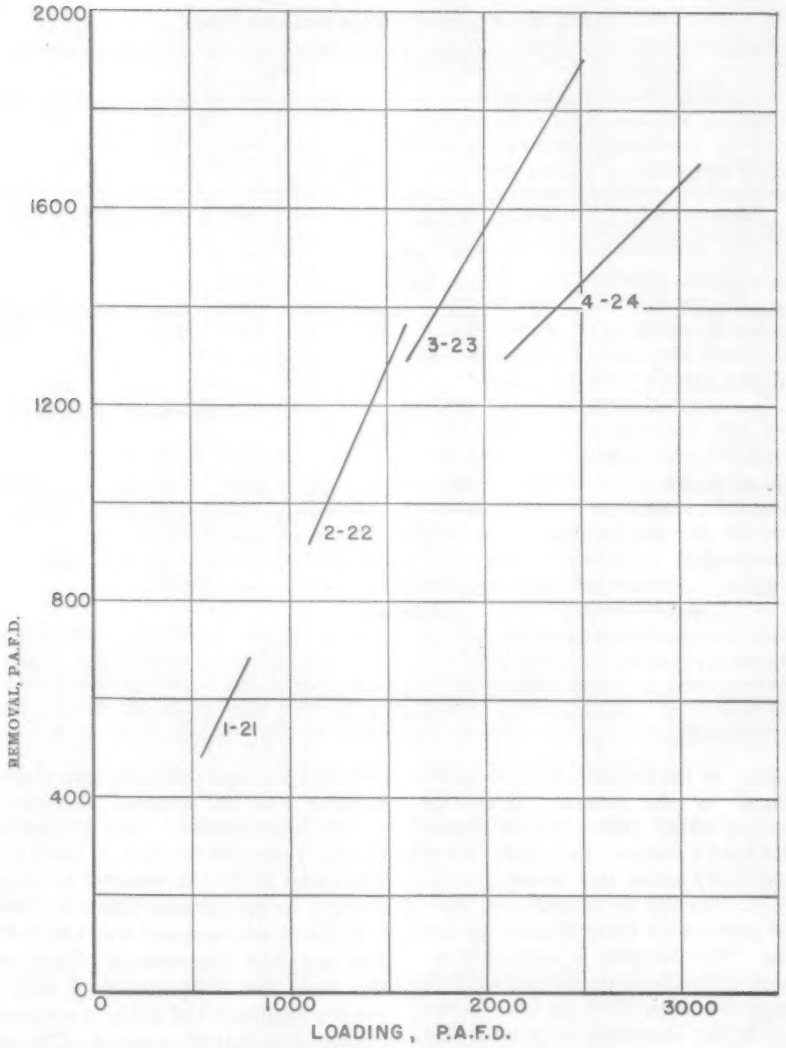

FIGURE 6.—B.O.D. removal in series filters.

hydraulic rate. Probably the selection of food by the organisms may be different. There is also the possibility that the composition of the zooglea on the two filters is different. No attempts were made to determine such differences.

The effect of an additional 3 ft. of filter depth may be shown by comparing a 6-ft. filter with a combination 6- and 3-ft. filter with the same organic loading. This is illustrated in Table V.

It will be noticed that with practically the same B.O.D. loading, the combination filter removed considerably more B.O.D. than the 6-ft. filter, even though the hydraulic rate was higher. The effect of hydraulic rate

TABLE III.—Average Results of Filters in Series

Item	Filters			
	1-21	2-22	3-23	4-24
Flow (m.g.a.d.)	4.46	8.92	13.38	17.83
B.O.D.				
Influent (p.a.f.d.)	666	1,329	2,010	2,629
Influent (lb. per cu. yd.)	0.41	0.82	1.25	1.63
Effluent (p.p.m.)	21	25	36	71
Removal (p.a.f.d.)	578	1,125	1,571	1,479
Removal (%)	86.8	84.7	78.2	56.3
Solids				
Influent (p.a.f.d.)	543	1,085	1,636	2,138
Influent (lb. per cu. yd.)	0.34	0.67	1.01	1.33
Removal (p.a.f.d.)	415	797	1,067	1,165
Removal (%)	76.4	73.5	65.2	54.5
Nitrogen				
	Infl.	1-21	2-22	3-23	4-24
Ammonia (p.p.m.)	26.2	17.5	18.8	21.7	24.8
Nitrite (p.p.m.)	0.0	0.6	0.6	0.3	0.1
Nitrate (p.p.m.)	0.3	6.5	4.9	1.7	0.3

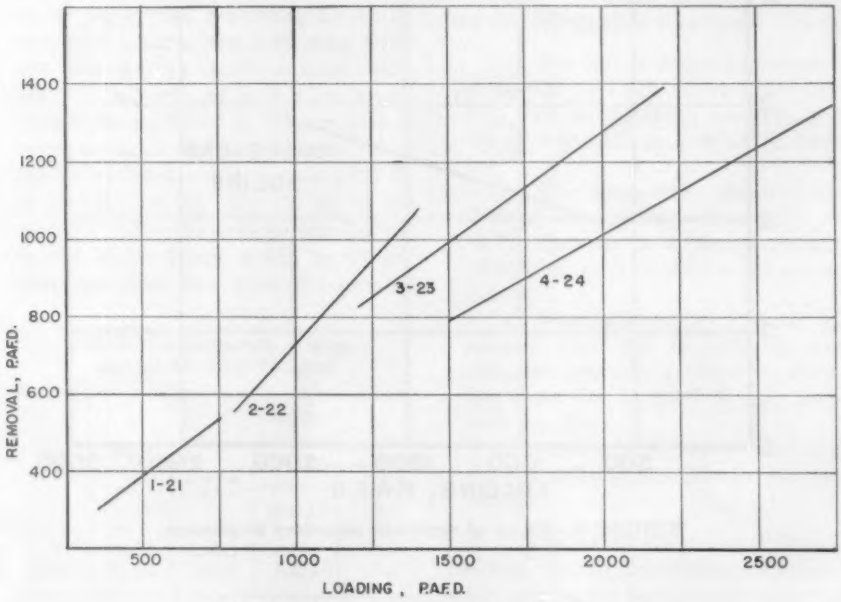

FIGURE 7.—Solids removal in series filters.

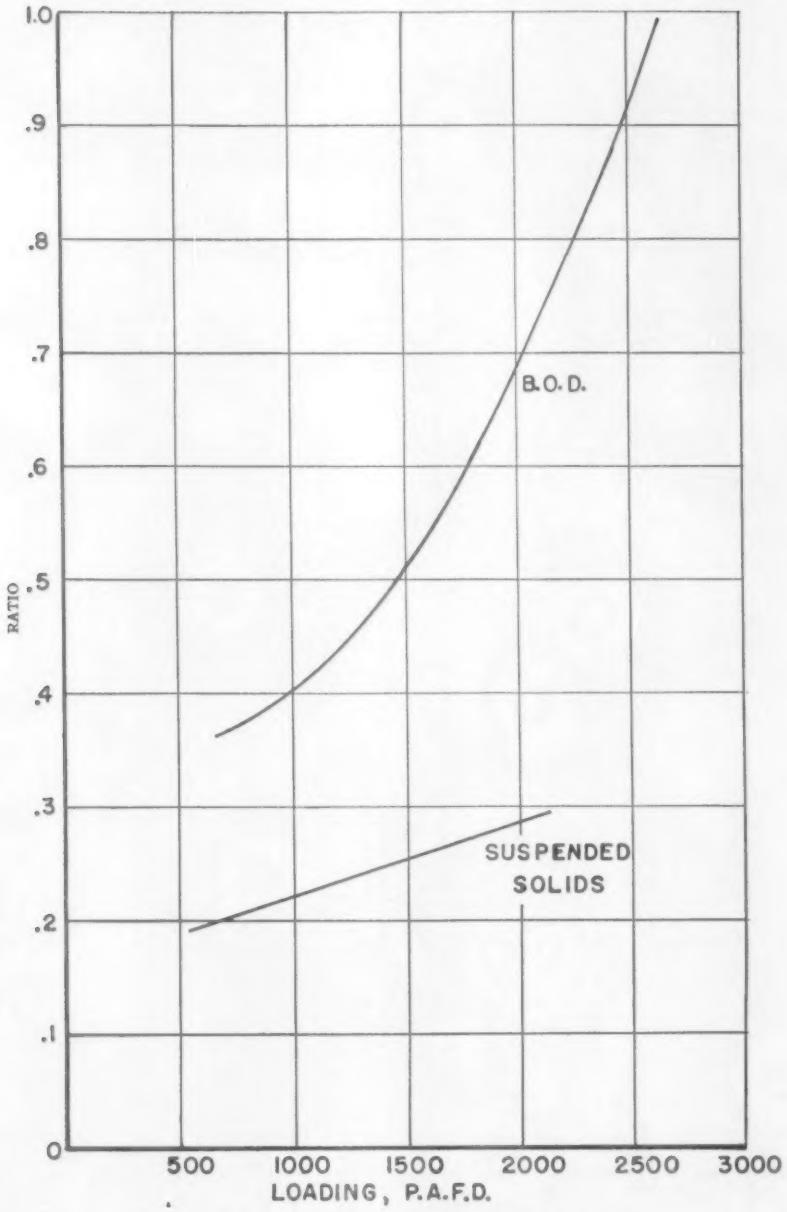

FIGURE 8.—Ratios of removals, secondary to primary.

TABLE IV.—Comparison of Primary and Secondary Filters

Filter No.	B.O.D. (lb.)		Solids (lb.)		Removal Ratios			
	Applied	Removed	Applied	Removed	Secondary: Primary		B.O.D.: Solids	
					B.O.D.	Solids	Primary	Secondary
1	2.20	1.40	1.79	1.15	—	—	1.22	—
21	0.80	0.51	0.64	0.22	0.364	0.191	—	2.32
2	4.39	2.53	3.59	2.15	—	—	1.18	—
22	1.86	1.18	1.44	0.50	0.466	0.233	—	2.36
3	6.63	3.14	5.41	2.80	—	—	1.12	—
23	3.49	2.05	2.61	0.74	0.653	0.264	—	2.77
4	8.66	2.49	7.08	2.98	—	—	0.84	—
24	6.17	2.48	4.16*	0.88	0.996	0.295	—	2.82

* Excluding three runs when sloughing was excessive.

upon B.O.D. removal has been previously demonstrated (7).

An example may be cited to show the advantages of series filtration over parallel filtration. Assume two filters in parallel, each of 0.1-acre area, and 6 ft. deep. At the loadings shown in Table V the flow would be 1.78 m.g.a.d., the loading would be 2,393 lb., and the removal 1,379 lb., leaving 914 lb. discharged in the effluent. If, on the other hand, a primary filter 6 ft. deep and a secondary 3 ft. deep without intermediate sedimentation were selected, the area of each filter would have to be increased by 33 per cent in order to obtain the same volume. But the series filters would remove 1,872 lb. of B.O.D., leaving only 521 lb. in the effluent. Thus, the pollution discharged by the series filters would be 43 per cent less than that from the parallel filters. There would probably be a difference in cost between the two plants, varying with local conditions, but it would be small. The important advantage would be the increased treatment secured by the series filters.

TABLE V.—Comparison of Single- and Double-Stage Filtration

Filter No.	Flow (m.g.a.d.)	B.O.D.		
		Loading (p.a.f.d.)	Removal	
			(p.a.f.d.)	(%)
2	8.92	1,994	1,149	57.6
3–23	13.38	2,010	1,571	78.2

Conclusions

1. Within the loading range of 1,000 to 4,000 lb. of 5-day B.O.D. per acre-foot per day applied to primary filters:

(a) The B.O.D. removal increased from 636 to 1,426 lb. per acre-foot per day at 3,000-lb. loading, but dropped to 1,130 lb. at 4,000-lb. loading.

(b) The percentage removal decreased consistently from 63.6 to 28.7, resulting in a poorer quality effluent ranging from 59 to 116 p.p.m. B.O.D.

(c) Suspended solids removal increased from 523 to 1,348 lb. per acre-foot per day at loadings ranging from 814 to 3,207 lb. per acre-foot per day.

(d) Roughing filters do not produce a satisfactory effluent for discharge.

2. The action of the primary filter is two-fold—partly flocculation of organic solids and partly biochemical oxidation

—whereas the action of the secondary filter is primarily oxidation.

3. The relation between the B.O.D. applied to and removed by the primary filters is hyperbolic in nature. Within loading limits under 4,000 lb. 5-day B.O.D. per acre-foot per day and hydraulic rates up to 18 m.g.a.d., this equation is

$$R = \frac{L}{0.000468L + 0.84}$$

4. Intermediate sedimentation in series filtration does not seem to be necessary, since no abnormal sludge was obtained.

5. At the loadings used in these studies no nitrification occurs in the primary filters. Nitrification does occur in the secondary filters, but at a decreasing rate up to loadings of 3,100 lb. of 5-day B.O.D. per acre-foot per day. At this loading no nitrification was evidenced (Figure 2).

6. At the same B.O.D. loading, series filtration affords a higher degree of treatment than single-stage filtration, even at a higher hydraulic rate.

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FEDERAL PERSONNEL CHANGES

Lt. Colonel Floyd L. Berry is now Chief, Sanitary Engineering Section, Medical Service Corps, Department of the Army, Washington, D. C. Colonel Berry has served as Chief, Sanitary Engineering Section, Environmental Hygiene Branch, in the Preventive Medicine Division of the Office of the Army Surgeon General, Washington, D. C., since August, 1955. Berry will function in a dual capacity, continuing in his assignment within the Surgeon General's office.

Dr. Leonard A. Scheele, Surgeon General of the Public Health Service, has resigned after 23 years of Federal service in public health. He has accepted the presidency of Warner-Chilcott Laboratories, a division of Warner-Lambert Pharmaceutical Co.

ENUMERATION AND SURVIVAL OF HUMAN TUBERCLE BACILLI IN POLLUTED WATERS *

I. DEVELOPMENT OF CULTURAL METHODS OF ENUMERATION

By H. Heukelekian and M. Albanese

The presence of tubercle bacilli in sanatoria sewage and the survival of those bacilli in sewage treatment processes and under natural stream conditions are of considerable interest from the standpoint of the public health hazards involved. To detect the pathogen, these studies have utilized methods which may be classified in general as (a) animal inoculation and (b) cultural.

The animal inoculation method has the advantage of giving positive identification of the pathogenic organisms by the development of tuberculous lesions but it is not a strictly quantitative method. The cultural method presents two problems: (a) suppression of most, if not all, of the other bacteria without materially affecting the pathogen and (b) identification of the pathogen from cultural and microscopic characteristics.

The wide ratio of saprophytes to tuberculosis organisms found in polluted substrates, such as sewage and surface waters, makes the use of a selective cultural method imperative. The suppression of the pathogen may be accomplished by (a) pretreatment of the sample or (b) incorporation of a selective suppressing agent in the culture medium. Pretreatment of samples with acid, alkali, or antiformin is known to decrease the number of tuberculosis organisms greatly. When done in the examination of sputum samples for diagnostic purposes, perhaps this reduction in numbers is not serious provided the pretreatment does not produce 100 per cent destruction of the pathogen. Such methods are, however, unsuitable for quantitative purposes intended to evaluate the effect of variables on the occurrence and survival of these organisms. The literature does not reveal satisfactory selective inhibiting agents for use in quantitative determinations, other than in the method developed by Pramer, Heukelekian, and Ragotzkie (1) for the estimation of *Mycobacterium avium*. Therefore, before the study of the occurrence and survival of tubercle bacilli could be undertaken, it was necessary to develop a suitable quantitative cultural method for their enumeration. It should be emphasized that the present study is concerned with *Mycobacterium tuberculosis* (*hominis*).

Experimental Methods and Procedures

For the experimental work in connection with the development of a suitable cultural method, a pure culture of *Mycobacterium tuberculosis* (*hominis*), $H_{37}R_v$, obtained from the American Type Culture Collection, was used. A fresh subculture of this organism was prepared by growing it in Dubos liquid medium (2) containing 0.05 per cent "Tween 80" and 0.5 per cent bovine albumin fraction. Dubos oleic acid agar was used as the basic medium in the studies.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University.

The serial inoculations of the sample were made by: (a) spreading 1 ml. of the inoculum over the surface of solidified agar, (b) incorporating 1 ml. of the dilution in the melted medium in the plate, and (c) placing a droplet (0.025 ml.) on the surface of a solidified agar surface according to the technique developed by Fenner (3). All plates were incubated at 37° C. The incubation periods were two weeks for surface inoculation methods and four to six weeks for pour plate techniques.

Results

Use of Antibiotics

In the first experiment, two antibiotics, penicillin and grisein, were incorporated in the agar medium separately in different concentrations and droplet inocula of suitable dilutions of *Mycobacterium tuberculosis* (*hominis*) $H_{37}R_v$ were placed on the surface of the solidified agar. The results of this experiment are given in Table I and they show that penicillin, up to 100 units per milliliter, had no effect on the numbers of the organism used, but that 125 units per milliliter suppressed the organisms completely. Grisein had no suppressing effect on the growth of the pathogen; with higher concentrations of it, there was a gradual decrease in the number of organisms recovered. The inhibiting concentrations of both of these antibiotics were found to be considerably higher for the human tuberculosis organism than for *Mycobacterium avium* (1).

TABLE I.—Effect of Penicillin and Grisein on *Mycobacterium tuberculosis* (*hominis*) $H_{37}R_v$*

Penicillin		Grisein	
Units (per ml.)	Number of Organisms (millions per ml.)	Units (per ml.)	Number of Organisms (millions per ml.)
0	0.97	0	0.97
5	1.15	10	1.37
10	1.19	30	1.43
25	1.09	50	—
50	1.06	70	1.26
75	0.96	90	1.20
100	1.00	100	1.00
125	0	125	0.83
150	0	150	0.85
175	0	175	0.75
200	0	200	0.68

* Antibiotics incorporated separately on Dubos oleic acid agar and droplet inocula placed on the surface of solidified agar. Average results from duplicate counts showing 30 to 100 colonies.

The increase in numbers of the tubercle bacillus with the addition of 10 to 90 units of grisein is considered significant, since the error in this method of counting according to Fenner (3) is ± 15.8 per cent. The increase in the number of tubercle bacilli with these concentrations of grisein could be attributed to a loss of potency of this drug and its possible use for growth.

The effect of penicillin and grisein, used separately and together, on the growth of sewage organisms is presented in Table II. The suppression of the sewage saprophytes did not exceed 50 to 60 per cent when using 100 units of penicillin per milliliter of agar. There is no indication that grisein, up to 150 units per milliliter, had a suppressing effect on the saprophytes; in fact, there is again an increase in the numbers of organisms with various concentrations of grisein over those obtained from the control plates. These results are in agreement with the previous observations made on the increase in numbers of *M. tuberculosis* (*hominis*) with the use of grisein. It further appears that when grisein is used in conjunction with penicillin the degree of suppression obtained by the latter is reduced.

It was concluded that sufficient suppression of the sewage organisms could not be obtained by the use of these antibiotics, either singly or together, at concentrations which would at the same time not materially affect the growth and the recovery of the pathogen. Accordingly, a study was made of the ef-

TABLE II.—Effect of Penicillin and Grisein Used Separately and Together on the Growth of Sewage Organisms*

Penicillin			Grisein			Penicillin and Grisein			
Dosage (units/ml.)	Growth of Organisms (millions/ml.)		Dosage (units/ml.)	Growth of Organisms (millions/ml.)		Dosage (units/ml.)		Growth of Organisms (millions/ml.)	
	6 Days	12 Days		6 Days	12 Days	Penicillin	Grisein	6 Days	12 Days
0	2.07	2.24	0	2.07	2.24	50	100	1.68	1.71
25	1.00	1.02	50	2.48	2.73	75	100	2.12	2.14
50	0.96	0.99	100	2.56	2.82	50	200	2.03	2.05
75	0.91	0.94	150	2.40	2.76	75	200	1.87	1.94
100	0.62	0.83	—	—	—	—	—	—	—

* Culture medium—Dubos oleic acid agar medium 1 ml. portions of antibiotic and inoculum placed on opposite sides of petri dishes and melted agar poured over them. Concentrations of antibiotic expressed on the basis of actual concentrations in agar.

fectiveness for this purpose of other antibiotics, namely, terramycin hydrochloride, terramycin sulfate, chloramphenicol, and polymyxin B, when incorporated in Dubos oleic acid medium in various concentrations. Droplets of serial dilutions of a pure culture of *M. tuberculosis* (*hominis*) were placed on the solidified agar. In another series, 1 ml. of serial dilutions of sewage was incorporated in Dubos oleic acid agar containing different concentrations of the antibiotics. The results given in Tables III and IV show that: (a) polymyxin B was unable to prevent the growth of air-borne contaminants and thus was useless for the enumeration of the pathogen, (b) chloramphenicol did not affect the numbers of tubercle bacilli at concentrations of 1.0 and 0.1 μg. per milliliter, but at the same time these concentrations did not suppress the growth of sewage organisms materially (a concentration of 10 μg. per milliliter was required to suppress the sewage organisms but this concentration also suppressed the pathogen); (c) 1 μg. per milliliter of terramycin sulfate gave a 42.7 per cent suppression of the pathogen and 59.5 per cent reduction of sewage bacteria (a higher concentration, 10 μg. per milliliter, of this antibiotic gave nearly total suppression of both types of or-

TABLE III.—Effect of Terramycin and Chloramphenicol on the Growth of *Mycobacterium tuberculosis* (*hominis*) $H_{37}R_v$*

Antibiotic (μg./ml.)	Number of Organisms (millions per milliliter)		
	Terramycin Hydrochloride	Terramycin Sulfate	Chloramphenicol
0	2.39	2.39	2.39
10^3	0	0	0
10^2	0	0	0
10	0	0	0
1	0.79	1.37	2.12
0.1	†	†	†

* Growth on Dubos oleic acid agar. In tests with Polymyxin B, all plates were contaminated and no results are reported.

† Organisms were too numerous to be counted.

TABLE IV.—Effect of Terramycin and Chloramphenicol on Sewage Organisms*

Antibiotic (μg./ml.)	Number of Organisms (millions per milliliter)		
	Terramycin Hydrochloride	Terramycin Sulfate	Chloramphenicol
0	2.25	2.25	2.25
10^3	0	0	0
10^2	0	0	0.05
10	0.08	0.06	0.22
1	1.14	0.91	2.05
0.1	2.17	1.79	2.30

* Growth on Dubos oleic acid agar.

ganisms), and (d) terramycin hydrochloride behaved in a manner similar to that of the sulfate.

None of these antibiotics, therefore, was suitable for selective killing of sewage organisms for the purpose of enumeration of tuberculosis organisms.

Pretreatment of the Sample by Heat

An attempt was made to effect selective killing of the sewage saprophytes by heat treatment of the sample. A diluted suspension of a culture of *M. tuberculosis* (*hominis*) was heated in a water bath at 50° C. for periods of 20, 40, and 60 min. and the numbers of the pathogen determined. The results showed that heating to 50° C. for as little as 20 min. reduced the number of tubercle bacilli by 76 per cent, for 40 min. by 91 per cent, and for 60 min. by 100 per cent. Thus, heating the sample was not a suitable method of pretreatment for the purpose of enumeration of tubercle bacilli in polluted waters.

Pretreatment of the Sample by Chlorination

Controlled chlorination, when used to disinfect sewage, will give 99.9 per cent suppression of coliforms and other similar organisms. Since human tubercle bacilli are known to be much more resistant to chlorine then nonsporeforming saprophytic organisms, it was considered possible to obtain selective killing of sewage organisms by careful and controlled chlorination without materially affecting the human tubercle bacilli.

To explore this possibility, a sample of sewage was treated with various known amounts of chlorine. After 30 min., the residual chlorine was determined by the orthotolidine method and the residual in the balance of the sample was destroyed by the addition of sodium sulfite. Three series of tests were run. In Series I and II sterilized sewage was inoculated with a pure culture of *M. tuberculosis* (*hominis*). The first of these two series was sterilized by autoclaving and the second by ultraviolet light. In these two tests, there were no contaminating organisms to contend with because each test was designed to show the effect, if any, controlled chlorination had on the pathogen itself. In the third series, a culture of the pathogen was added to unsterilized sewage. The results from the three series are presented in Table V. In the first series, a residual of 0.1 p.p.m. of chlorine had no effect on the numbers of the pathogen, 0.2 p.p.m. residual had only a slight effect, and 0.5 p.p.m. reduced the numbers by about 16 per cent. In the second series, the reductions of the number of tubercle bacilli were 23.5, 27.5 and 41.0 per cent with 0.2, 0.5 and 1.0 p.p.m. chlorine residuals, respectively. In the final series in unsterilized sewage, the reductions were 27.0, 27.5 and 39.5 per cent with 0.2, 0.5 and 1.0

TABLE V.—Effect of Chlorination of Sewage on the Recovery of *Mycobacterium tuberculosis* (*hominis*) $H_{37}R_v$* and the Suppression of Sewage Organisms

Substrate	Type of Organisms	Chlorine residuals (p.p.m.)				
		0	0.1	0.2	0.5	1.0
		Organisms (millions/ml.)				
Series I: Sterile sewage (autoclave)	T.B.	0.34	0.36	0.32	0.28	—
Series II: Sterile sewage (ultraviolet)	T.B.	0.51	—	0.39	0.37	0.30
Series III: Nonsterile sewage	T.B.	0.65	—	0.44	0.435	0.38
Series III: Nonsterile sewage	sewage	2.62	—	0.022	0.010	0.01

* A suspension of $H_{37}R_v$ added to sewage in series I, II and III.

p.p.m. chlorine residuals, respectively. The last series also indicates that these residuals permitted the reduction of the numbers of sewage saprophytes by more than 99 per cent.

Accordingly, for subsequent work using prechlorination as a pretreatment method of the sample, the procedure selected and followed was to chlorinate the sample to a residual of 1.0 p.p.m. for 30 min. before dilution and plating for the purpose of enumeration of tubercle bacilli.

Pretreatment with Bradosol

Since Wagener, Mitscherlich, and Reuss (4) reported the successful use of Bradosol, a quarternary ammonium compound, for the recovery of tubercle bacilli from sewage, it was considered advisable to determine the effect of various concentrations of this compound on the recovery of tubercle bacilli and sewage saprophytes. Bradosol was added to sewage and the sample was allowed to stand for a period of 20 min. before dilution. Tubercle bacilli were enumerated by incorporating 1 ml. of a serial dilution in Dubos oleic acid agar.

The recovery of tubercle bacilli when artificially added to ultraviolet sterilized sewage and the suppression of sewage saprophytes in unsterilized sewage upon treatment with various concentrations of Bradosol are given in Table VI. When sewage was treated with 350 p.p.m. or more of Bradosol, there was no growth of sewage bacteria on the plates inoculated with 1 ml. of undiluted sewage. With this concentration of Bradosol, the recovery of tubercle bacilli was about 70 per cent; with 500 p.p.m. of Bradosol, the recovery was about 80 per cent. No mold growths were obtained at the higher concentration of Bradosol.

The experiment was repeated two more times under essentially the same conditions using only 500 p.p.m. of Bradosol. Since the recoveries on the second and third runs of tubercle bacilli were 68 and 73 per cent, respectively, it was decided to select 500 p.p.m. Bradosol because it would eliminate all contaminating organisms from the plates and enable the detection of tubercle bacilli in 1 ml. of undiluted sewage without interference from saprophytic organisms. The complete suppression of these organisms was considered more important than the somewhat incomplete recovery of the tubercle bacilli (70 to 80 per cent).

TABLE VI.—Recovery of *Mycobacterium tuberculosis* (*hominis*) $H_{37}R_v$ and the Survival of Sewage Saprophytes by Pretreatment of Sewage with Bradosol

Bradosol (p.p.m.)	Recovery of Tubercle Bacilli* (%)	Saprophytes Remaining† (%)
50	94.5	83
100	90.5	48
200	81.3	12
350	69.6	0‡
500	79.0	0
1,000	51.3	0
2,000	42.0	0
3,500	14.2	0
5,000	<10.0	0

* Pure cultures added to ultraviolet sterilized sewage.

† Sewage not otherwise treated or inoculated with pathogen.

‡ Indicates the absence of colonies in plates inoculated with 1 ml. of undiluted sewage.

The advantages of the Bradosol method over chlorination pretreatment of sewage for selective killing are as follows: (a) less time-consuming, (b) smaller volume of sample required and (c) the largest volume of a sewage sample in which the number of tubercle bacilli can be determined is 1.0 ml. instead of 0.1 ml. as in the chlorination method.

Statistical Evaluation

A suspension of *M. tuberculosis* (*hominis*) was diluted with 0.1 per cent bovine albumin in physiological saline. From this diluted stock, 10 identical series of dilutions were plated in duplicate in Dubos oleic acid agar medium.

TABLE VII.—Statistical Evaluation of the Dilution and Plating Techniques

Dilution Series	Replicate Plate Counts, $\times 10^{5*}$	
	Plate No. 1	Plate No. 2
1	40	42
2	37	†
3	36	38
4	37	35
5	29	34
6	35	†
7	33	37
8	27	31
9	29	23
10	33	30

* Counts made in 10^5 ml. of sample.
† Spoiled plates.

The primary data are given in Table VII. The standard deviation as calculated from these data is ± 5.8. At the 95 per cent confidence limit, a single determination is ± 37 per cent of the average value.

Identification of Cultures

Colonies were picked at random from typical ones growing on plates inoculated with either artifically or naturally infected substrates and transferred to Dubos "Tween 80", an albumin liquid medium. After a 10 to 14-day period, the colonies were stained with acid-fast stain according to procedures recommended by the Biological Stain Commission. Of the 24 samples, only six were found to be acid-fast negative (Table VIII).

The small number of acid-fast negative colonies is possibly due to the effect of either prechlorination or Bradosol pretreatment techniques affecting the staining characteristics. Two of the samples were micrococci. If the acid-fast cultures giving a negative stain are taken as a basis for comparison, the counts made by visual identification of the colonies on the plate average about 30 per cent higher than actual (6 acid-fast negative and 18 acid-fast positive). In the artifically inoculated substrates, the discrepancy between the acid-fast negative cultures and visual identification is smaller (2 out of 11 cultures or about 20 per cent). Again, in the breakdown of the naturally contaminated substrates, only two out of a total of six cultures obtained from untreated sanatoria sewage failed to give the positive acid-fast stain. In chlorinated sanatoria effluents, the discrepancy was greater (two positive out of a total of four samples).

Twenty-seven cultures were transferred to Lowenstein-Jensen egg medium slants and sent to the New York State Department of Health for identification by guinea pig inoculations. These cultures were digested in 4 per cent NaOH for 30 min. to 4 hr. prior to staining and animal testing. Only 8 out of 13 cultures obtained by inoculating a pure culture of the tubercle bacilli into sterile substrates gave positive guinea pig reaction. It, therefore, becomes necessary to disregard the verification of tests attempted. Treatment of the cultures with NaOH was believed to be too drastic in comparison

TABLE VIII.—Identification of Cultures by Acid-Fast Stain and Animal Inoculations

Substrates	Cultures (no.)	Acid-Fast Positive Cultures (no.)	Positive Cultures on Animal Inoculation (no.)
Naturally contaminated:			
Untreated sanatoria sewage	6	4	0
Chlorinated sanatoria effluent	4	2	0
Recovery stream	1	1	0
Total	11	7	0
Artificially contaminated sewage	13	11	8
Total	24	18	8

with the same techniques applied to sputum samples containing mucous material.

Discussion

The principal difficulty in developing a suitable selective culture method for enumeration of the tuberculosis bacillus in sewage or polluted waters is caused by the relatively few numbers of the pathogen as opposed to the very high numbers of saprophytic organisms. Granting that the pathogen has a higher resistance to selective agents than the saprophytes, the problem still is one of how to inhibit almost completely the growth of saprophytes without materially reducing the number of pathogens. Sewage contains approximately a million saprophytic bacteria per milliliter which can, by a suitable selective agent, be suppressed by 99 per cent. The 10,000 surviving bacteria per milliliter would produce 10 colonies in a 1 to 1,000 dilution. At least 1,000 tuberculosis bacilli per milliliter would have to be present to produce one colony among the 10 saprophytic colonies. If, under assumed conditions, the numbers of the tuberculosis organism were 100 per milliliter, the organisms would probably not appear on the plates. The presence of fewer than 1,000 tuberculosis organisms per milliliter can only be detected by suppressing the saprophytes more than 99 per cent without materially affecting the number of pathogens. This was the aim of this investigation but by the incorporation of a number of antibiotics in the culture medium, this rigid requirement was not fulfilled.

Pramer, Heukelekian, and Ragotzkie (1) showed that a selective medium with the incorporation of five units of penicillin and 50 units of grisein per milliliter of medium had little if any effect on the recovery of *Mycobacterium avium*. However, these antibiotics did suppress the sewage organisms by 74 to 82 per cent. Concentrations of penicillin greater than five units per milliliter resulted in substantial reductions in the recovery of *Mycobacterium avium*, 40 units per milliliter reduced the recovery to 18 per cent. The results of the present study indicate that *M. tuberculosis* (*hominis*) can withstand concentrations of penicillin as great as 100 units per milliliter without affecting their recovery. As grisein had apparently deteriorated by storage, it had no effect on the recovery of the pathogen or the saprophytes up to 100 units per milliliter. In fact, the recovery of saprophytes with 100 units of grisein per milliliter of medium was higher than when no grisein was used. The antibiotic effect on the saprophytes was confined only to the penicillin which at 100 units per milliliter did not reduce their numbers sufficiently to permit the use of low dilutions of the sample for counting the pathogens without serious interference from overgrowth of sewage saprophytes. A fresh preparation of grisein was not obtainable.

Chlorination of the sample under carefully controlled conditions for selective killing prior to plating did not prove highly successful because 1.0 p.p.m. residual chlorine produced only a 99 per cent suppression of sewage saprophytes, whereas it reduced the recovery of the pathogen by as much as 50 per cent.

Pretreatment of the sample with 500 p.p.m. of Bradosol gave complete suppression of sewage organisms with recoveries of 70 to 80 per cent of the pathogen. By this method, it is possible to detect the presence of tubercle bacilli in as little as 1 ml. of the original sample.

The verification of 27 cultures, selected as tuberculosis organisms by acid-fast staining, indicated that either the staining ability of the pathogen was altered by pretreatment methods or that visual identification did not exclude a certain number of saprophytic bacteria with similar colonial characteristics.

Summary and Conclusions

Several selective culture methods were tried for the enumeration of relatively few tubercle bacilli among a great many saprophytic bacteria commonly found in sewage and other polluted waters. The methods tried were: (a) antibiotics incorporated in the culture medium, (b) pretreatment of the sample by controlled chlorination and (c) pretreatment of the sample with Bradasol, a quartenary ammonium compound. The criterion of success was the complete suppression of the saprophytes with an effect on the recovery of tuberculosis organisms such that the presence of the pathogen could be detected in 1 ml. of the original sample. The work was done by the artificial inoculation of sewage with *M. tuberculosis* (*hominis*).

The results warrant the following conclusions:

1. Penicillin and grisein used in the amount of 100 units per milliliter did not effect the recovery of the tuberculosis organism but at 125 units per milliliter, these antibiotics completely suppressed it. At 100 units per milliliter sufficient suppression of sewage saprophytes was not obtained to make a suitable selective culture medium.

2. Terramycin (both the hydrochloride and the sulfate) in amounts of 1 μg. per milliliter greatly reduced the recovery of the tubercle bacilli but it did not satisfactorily suppress the sewage organisms. With a 10 μg. per milliliter concentration, the suppression of sewage organisms was substantial (96 per cent) but so was the suppression of the tubercle bacilli. Chloramphenicol was even less satisfactory than terramycin. This antibiotic in concentrations of 1 μg. per milliliter had very little effect on either the sewage saprophytes or the tuberculosis organism; 10 μg. per milliliter suppressed the pathogen completely and the saprophytes substantially.

3. Chlorination of the sample to an orthotolidine residual of 0.5 and 1.0 p.p.m. after a 30 min. contact period gave a substantial but not complete suppression of sewage saprophytes and 50 per cent recovery of *M. tuberculosis* (*hominis*).

4. Pretreatment of the sample with 500 p.p.m. of Bradosol for 20 min. gave a complete suppression of sewage saprophytes and a 70 to 80 per cent recovery of *M. tuberculosis* (*hominis*).

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VACUUM SLUDGE FILTRATION

I. INTERPRETATION OF RESULTS BY THE CONCEPT OF SPECIFIC RESISTANCE

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Any method of measuring the filterability of sewage sludges should lead to the evaluation of a parameter which is independent of as many variables as possible. Such a parameter will be of fundamental importance in comparing the resistance to filtration of different types of sludges and this will enable operators and research workers to compare sludges in an unbiased fashion. It would be of added value if such a parameter could be used in applying laboratory-scale results to full-scale design and the operation of vacuum filters and filter presses.

The Buchner funnel test in its present forms does not fulfill the foregoing conditions. The test usually involves filtration of a given volume of sludge under a vacuum until a cake is formed which eventually cracks with a resultant drop in pressure. The time required to reach this point is frequently taken as a measure of the filterability of the sludge. It is obvious that the time taken before the cracking point is reached depends upon a number of variables. These are as follows:

1. The initial solids content of the sludge.
2. The volume of sludge filtered.
3. The area of the filtering surface.
4. The pressure at which the filtration is carried out.

In much of the published work on filtration these variables are not recorded, and even in the cases where some of the variables are recorded it is not possible to make any direct comparison of the results obtained. Table I, giving examples of Buchner funnel tests carried out by various workers, illustrates the wide variation in the variables listed.

Results obtained by these methods are not directly applicable to full-scale operation and can only serve the purpose of arbitrarily comparing the treatments which any one worker has used. In view of the disadvantages of the Buchner funnel test as generally used and the additional drawback that it is not possible to compare sludges having small differences in filterability, a point of importance when carrying out research on sludges, an investigation into the application of the various theories of filtration to the filtration of sewage sludges was carried out.

The theoretical approach to filtration started by Hatschek (9) in 1908 was developed by various workers until it was satisfactorily completed by Ruth and his co-workers (10) and Carman (11) (12). Ruth and Carman published their results in 1933 and established the fact that the relation between filtrate volume obtained and time of filtration was of parabolic form. These workers also introduced the concept of "average specific resistance." This term denotes the resistance of unit weight of cake per unit area at a given pressure and is expressed in centimeters per gram. Average specific resistance is a parameter having the properties previously described. It was not until

TABLE I.—Comparison of Variables Listed in Sludge Filtration Tests

Date	Worker	Ref.	Diameter of Funnel	Vol. of Sample	Pressure (cm. Hg.)	Filter Medium	Initial Sludge Solids	Final Cake Solids	Reported as	Notes
1923	Wilson, Copeland, and Heisig	(1)	—	500 cc.	Not given	—	After addition of coagulant and dilution: 1% solids	—	—	Alteration of filter area and pressure alter the constant of proportionality
1925	Thompson	(2)	8.9 cm. (3½ in.)	300 cc. after mixing with reagent	60 cm.	No. 3 Whatman	—	—	Time to cracking	
1934	Genter	(3)	9 cm.	200 g. of sludge made up to 220 g. with aq. dist. or coagulant	74	No. 4 Whatman	Not given	Not given. Total vol. of filtrate recorded	Filtration rate	Filtration rate in cc. per sec.
1936	Ardern and Lockett	(4)	9 cm.	100 ml.	15	No. 4 Whatman	Adjusted to 0.70% dry organic matter	Can be deduced from results	Time to obtain 85 ml. of filtrate	Used for activated sludge
1938	Thompson and Proctor	(5)	11.5 cm. (4½ in.)	300 ml.	6	No. 3 Whatman	Not given	Not given	Time to cracking	Approx. 1/5th full-scale time to press
1947	Wishart, Jepson, and Klein	(6) (7)	9 cm.	200 ml.	56	No. 4 Whatman	Eliminated by filtration rate	Given in most cases	Filtration rate: g. dry sludge solids filtered per min.	Filtration rate in g. per min.
1953	Bruce, Clements, and Stephenson	(8)	51 cm. (20 in.)	1 gal.	38	Wool cloth	Not always given	Given	Time to cracking	Thickness of cake given in the results

1938 that a theoretical approach was mentioned in the literature by Thompson and Proctor (5). These workers, after referring to Carman's work, continued to use the Buchner funnel tests using arbitrary conditions. Coackley, however, in 1953 and 1955 (13) (14) applied Carman's theory to sludge filtration and found that the concept of specific resistance was of great use in expressing filtration results.

Recently, interest has again turned to the theoretical approach to filtration. In 1952 Halff (15) made an attempt to describe filtration by analogy with classical heat transfer theory. This approach does not allow the use of so simple a concept as average specific resistance and it is more difficult to apply to the results than Carman and Ruth's theory. Grace (16) retained the concept of average specific resistance, but his method for obtaining a value for this quantity from compression-permeability data has the disadvantage of being time consuming when applied to sewage sludges. A much greater disadvantage, perhaps, is that it involves the use of apparatus not generally available in sewage works laboratories.

The theories of Ruth, Carman, Halff and Grace are briefly described in the next section, with the differences in approach indicated.

Theories of Filtration

Theories of Ruth and Carman

Ruth and Carman agree about the treatment for rigid cakes, showing that filtration results follow a parabolic law. Poiseuille's law and D'Arcy's law for a

bed of fixed thickness can be combined and written as follows:

$$\frac{dV}{d\theta} = \frac{P\,A}{u\,R} \qquad (1)$$

in which

$\frac{dV}{d\theta}$ = rate of flow of liquid across the bed;

P = pressure difference across the bed;

A = area of the bed;

u = viscosity of the filtrate; and

R = a resistance proportional to the thickness of the bed.

If, for a rigid cake, the resistance of unit weight of the cake per unit area is r'' and if v is the constant of proportionality between the volume of filtrate and the volume of solids deposited therefrom

$$R = r''\frac{V\,v}{A} \qquad (2)$$

in which V is the volume of filtrate. Substituting this value in Eq. 1 and integrating gives

$$V^2 = \frac{2\,P\,A^2\,\theta}{ur''v} \qquad (3)$$

Ruth then discusses the distribution of pressure, and consequently voids or permeability for a compressible cake, and concludes that there is insufficient information to derive, theoretically, an equation relating rate of flow to pressure. He shows that in experimental filtration all sludges, whether compressible or not, conform to the relation

$$(V + C)^2 = K(\theta + \theta_0) \qquad (4a)$$

in which C represents the volume equivalent to the initial resistance of the cloth together with the volume required to fill the filtrate lines, etc., and θ_0 represents the time for this to take place. It is then shown that from experiment all materials act as if a constant average resistance is added for equal volumes of filtrate discharged; thus a value for average specific resistance is obtained. The constant K in Eq. 4*a* has the value

$$K = \frac{2\,P\,A^2}{urv} \qquad (4b)$$

whence

$$r = \frac{2\,P\,A^2}{ukv} \qquad (5)$$

Ruth's value of v is based on the assumption that equal weights of filtrate deposit equal weights of solids, and that this can be found from a knowledge of the solids left in the cake when filtration is complete. (Taken to be the stage of cake crack.) This raises the difficulty that filtration may be stopped at different stages (that is, before cake cracking) and yet a cake will have formed in which all the solids are embraced. The value of v may be written as

$$v = \frac{\rho\,(100 - C_i)(100 - C_f)}{100(C_i - C_f)} \qquad (6)$$

in which

ρ = density of the filtrate;

C_i = initial moisture content of the sludge; and

C_f = final moisture content of the cake.

This suggests that specific resistance is dependent on the final solids in a cake, and that if a filtration is stopped at 75 per cent moisture in the cake the value of the specific resistance would differ considerably from the value obtained if the filtration were continued to 70 per cent moisture.

If the assumption is again considered, it will be seen that the weight of solid in the cake must be accompanied by an equivalent weight of liquid. Hence, the weight of the solid deposited in the cake will be proportional to the total weight of liquid or

$$v = \frac{K(100 - C_i)}{C_i} \qquad (7)$$

If C_f, the final cake moisture, did not vary, Eqs. 6 and 7 would vary identi-

cally with C_i. However, variations in C_f alter Eq. 6, suggesting that the derivation of v is based on false premises.

Carman's approach (11) is different from that of Ruth in that he assumes that the pressure distribution through the cake is known. It is further assumed that specific resistance changes through the cake with pressure in the same way that the average specific resistance for the whole cake changes with pressure. He also considers the resistance and compressibility of the filter cloth separately, whereas Ruth shows them as an equivalent initial volume.

Carman assumes that the specific resistance at a point in the cake varies according to the formula

$$r = r_1 P^S$$

or, alternatively,

$$r = r_2(1 + \alpha P)$$

in which S and α are constants, and that for either type of compressibility equation the rigid cake formula holds when the variation of r with P is taken into account.

Carman's basic equation for a rigid cake is

$$\frac{dV}{d\theta} = \frac{P A^2}{u(r_i v V + R A)} \qquad (8)$$

in which R is the initial resistance per unit area for a liquid of unit viscosity. Integration at constant pressure gives

$$\theta = \frac{u r_i v}{2 P A^2} V^2 + \frac{u R}{P A} V \qquad (9)$$

or

$$\frac{\theta}{V} = \frac{u r_i v}{2 P A^2} V + \frac{u R}{P A} \qquad (10)$$

Eq. 10 gives a straight line when $\frac{\theta}{V}$ is plotted against V with a gradient $b = \frac{u r v}{2 P A^2}$. The specific resistance, r, is obtained by substitution in

$$r_i = \frac{2 P A^2}{u v} b.$$

In any experimental determination of r, θ and V should not be measured from the beginning of filtration. It is necessary to record the filtrate volume after a thickness of cake having a resistance equal to the resistance of the filter cloth has been deposited. This reduces the errors introduced by assuming that the compressibility of the cloth is the same as that of the sludge. Carman indicates that although it is possible to obtain values of the initial resistance from the experimental results, the values will not be very accurate. This is not important, however, as the function of this term is to suggest the correct mode of plotting the results to obtain accurate and consistent values of r.

Eq. 8 is also applicable to compressible cakes like those obtained from sewage sludges if r_i is regarded as a function of P. It is easier to express the sludge concentration by weight of dry cake solids per unit volume of liquid, c, than by volume of cake per unit volume of filtrate, v. Eq. 8 therefore becomes

$$\frac{dV}{d\theta} = \frac{PA^2}{u(rcV + RA)} \qquad (11)$$

in which $rc = r_1 v$, whence

$$r = \frac{2PA^2}{uc} b \qquad (12)$$

The similarity of Eqs. 5 and 12 is apparent. The equation used by Ruth in plotting filtration results is the differential equation derived from Eq. 4; that is,

$$2(V + C)dV = Kd\theta.$$

This may be expressed as

$$\frac{dV}{d\theta} = \frac{2V}{K} + \frac{2C}{K} \qquad (13)$$

Values of $\frac{d\theta}{dV}$ are plotted against V and a straight line is obtained of slope $2/K$ and having a negative intercept, C, on the V axis.

Ruth and Carman differ in their methods of expressing the pressure relations. Carman adopts $r = r_1 P^s$ and Ruth adopts $r = r_2(1 + r_3 P^s)$. Both of these equations are empirical, based upon experimental results. Carman admits that his formula is not perfect and shows curves for very compressible materials in which deviations from the formula occur. Ruth states that his equation does not enable low compressibilities to be evaluated with any degree of accuracy (for a rigid cake $S = 0$) and suggests that S should equal unity for low compressibilities. This is anomalous, as $S = 1$ denotes a completely compressible cake. For this reason Carman's relation is to be preferred.

Fourier-Type Equation

In 1952 Halff (15) found poor correlation between theoretical and practical results on rotary vacuum filters using the equations of Ruth (17) and Walker *et al.* (18). He found that Ruth's equation was to be preferred, but that it still did not predict the results accurately for sewage sludge. Halff developed an approach based upon Terzaghi's theoretical treatment of the consolidation of soils.

The derivation of Halff's equation is rather complex, but a study of the derivation establishes the fact that filtration follows the parabolic relationship until the cake reaches 80 per cent filtration or consolidation. For vacuum filtration there can be little consolidation before cake cracking occurs, although in a pressure filter a reasonable amount of consolidation may occur towards the end of a run. Halff's approach is more difficult to apply than that of Carman and Ruth and the dependence of the coefficient of filtration upon final cake moisture is a serious disadvantage.

Specific Resistance from Compression-Permeability Data

In 1953 Grace (16) published three papers dealing with filtration and centrifugation. The first two describe a method for arriving at a value for the specific resistance. The principle involved in Grace's approach is the measurement of specific resistance, r_p, for a cake with uniformly applied pressure stress, p, which is obtained by consolidation of the cake at that pressure and the subsequent determination of its permeability. He then obtains an expression for average specific resistance of the cake which depends upon the pressure drop across the cake, $P_2 - P_1$; an expression for the pressure drop across the septum, $P_1 - P_0$, involving a knowledge of the septum resistance is determined from a separate permeability experiment. This enables $P_2 - P_1$ to be evaluated as

$$P_2 - P_1 = (P_2 - P_0) - (P_1 - P_0) \qquad (14)$$

in which

P_0 = hydraulic pressure on discharge side of filter medium;

P_1 = hydraulic pressure on cake side of filter medium; and

P_2 = hydraulic pressure at exposed surface of filter cake.

The relation for average specific resistance is

$$\int_0^{P_2 - P_1} \frac{dP}{r_p} = \frac{P_2 - P_1}{r} \qquad (15)$$

The left-hand side of this Eq. 15 is integrated by Simpson's Rule using the compression-permeability data for the variation of $\frac{1}{r_p}$ with p, hence the value of r is obtained. Experiments have shown that values of specific resistance obtained in this way are within ± 10 per cent of the values obtained from constant pressure filtrations.

Grace suggests that the compression-permeability method of determining specific resistance should be used for the following reasons:

1. The determination of permeability over a complete range of pressures can be completed in a day.

2. The method enables the average specific resistance at any particular pressure within the range to be calculated and also takes into account the variation of compressibility at high pressures. It is shown that the variation of compressibility with pressure up to 2,700 lb. per sq. in. is not straightforward and that there is no relationship which will hold over the whole range.

In applying Grace's method to sewage sludges it has been found that a full range of tests cannot be carried out in one day. Grace states that consolidation occurs in periods of 2 to 15 min. In the case of sewage sludges periods of between 1 and 2 hr. are required to reach 90 per cent consolidation, and in many cases it is 24 hr. before the cake is fully consolidated. This greatly increases the length of time required to carry out the tests. The calculations involved are also laborious and involve a considerable amount of time.

Choice of Suitable Theory

From this brief summary and criticism of the filtration theories readily applicable to sewage sludges it can be seen that the simplest and most easily applicable theory is that of Carman. Consequently, it was decided to see whether experimental results would justify a more common usage of Carman's theory and the concept of average specific resistance.

Experimental Use of Carman's Theory

Apparatus

For routine laboratory work and for most research projects a simple piece of apparatus similar in most respects to the apparatus (Figure 1) used for Buchner funnel tests may be used. It can be seen from the theory that the requirements of the filtration tests are that (a) the filter area must be known accurately, (b) the pressure at which the filtration is carried out must be

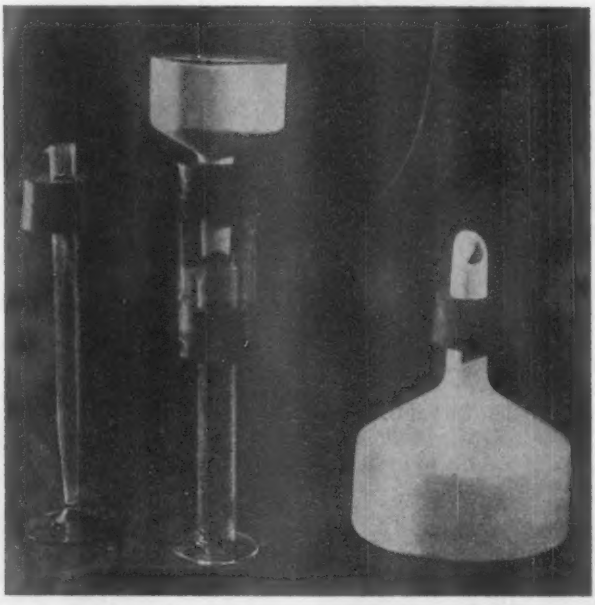

FIGURE 1.—Adaptor for Buchner funnel.

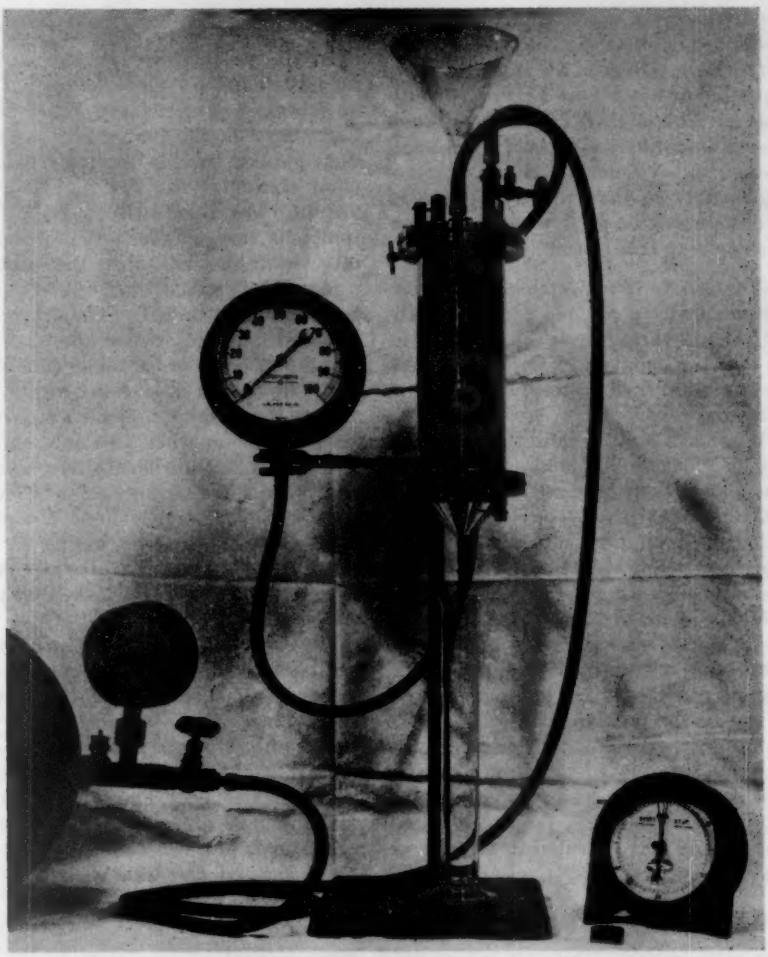

FIGURE 2.—Pressure filter assembly.

known, (c) the volume of filtrate must be measured at time increments from the commencement of the filtration test, (d) the ratio c must be determined (that is, the quantity of solids associated with 1 ml. of filtrate), and (e) the viscosity of the filtrate (this may, except in the case of very accurate work, be taken as that of water at the same temperature). The variables governed by the filtration equipment are as follows:

1. The filter area, which may be determined by direct measurement.

2. The pressure, which is readily kept constant by attaching a reservoir to the vacuum line, the pressure being measured by a mercury manometer attached to the reservoir.

3. The rate of filtration, obtained by measuring the volume of filtrate at known increments of time. The filtrate volume is found by using a measuring cylinder with a side arm instead of the

usual filter flask. If difficulty is experienced in obtaining measuring cylinders with a side arm, a connection such as that shown in Figure 1 may be readily made. This adapter has the advantage of enabling different sizes of funnel and measuring cylinder to be used interchangeably so that varying quantities of sludge may be used, depending upon the rapidity of filtration.

The results given in this paper were obtained with a piece of equipment designed to operate up to high pressures so that the behavior of sludges at pressures greater than atmospheric could be studied.

Figures 2 and 3 show the filtration vessel. The body, made from brass, was 9 in. long with an internal diameter of $3\frac{1}{4}$ in. Four thumb screws were provided at each end for quick assembly and dismantling. All the tappings were made through the top flange. A filling hole with a coarse thread was provided so that after pouring the sample into the vessel it could be closed rapidly. The pressure relief valve was necessary to release the pressure at the end of an experiment. The funnel assembly was designed to give adequate support to the filter medium while providing the shortest possible path for the filtrate. The filtrate was collected in a measuring cylinder of suitable size.

Experimental Technique

In the case of the Buchner funnel modification the tests were carried out as follows. A moistened filter paper was placed in the funnel and the vacuum applied so that the paper was in close contact with the funnel. The vacuum was then switched off. The sample of sludge under test was poured into the funnel and then the vacuum was slowly applied until the required pressure was attained. The volume of filtrate coming off the sample was then measured, after a suitable time had been allowed for a cake to form, every minute for 10 min., and then at 2-min. intervals for another 10 min. In the case of a well-conditioned sludge a large funnel and measuring cylinder were used so that a large volume of sludge could be used, thereby giving an increased depth of cake in order to enable sufficient readings to be taken to plot the graph.

When the second piece of apparatus was used the following procedure was adopted. The clean filter barrel was fixed tightly to the top flange by the four thumb screws, a funnel was placed in the filling hole, and the pressure relief valve was opened. The sludge sample was prepared and a suitable volume placed in a beaker. The funnel with the perforated disc and with the two

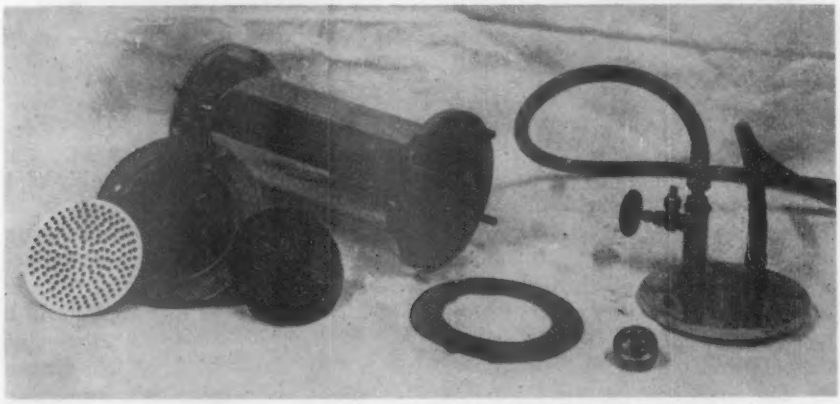

FIGURE 3.—Pressure filter parts, including drilled stainless steel supporting disc, funnel, filter body, gauzes, hard rubber packing ring, filter cap, and top flange plate.

gauzes in position was held under running water until thoroughly wet. A filter paper was then placed on the gauze. The funnel was fixed tightly to the filter barrel by four thumb screws and a suitable measuring cylinder was placed below the funnel outlet. The sample was then poured through the filling funnel and the stopclock started at −2 min. The funnel was removed, the filter cap closed, and the pressure inside the vessel raised to the required value. The filtrate volume was again measured at 1-min. intervals for the first 10 min. and then at 2-min. intervals for a further 10 min. It was considered that, in general, the time from −2 min. to zero was a suitable length of time to allow for the formation of a cake with a resistance equal to or greater than that of the filter medium. By adopting the procedure of wetting the gauzes and filter paper, no time lag was noted between applying the pressure and the appearance of filtrate, as the first drop of filtrate expelled its equivalent volume from the water held by the gauzes.

Method of Calculating Specific Resistance

The graph of $\frac{\theta}{V}$ *versus* V is plotted from the experimental results. The volumes of filtrate used are obtained by subtracting the volume obtained between −2 and 0 min. from all the subsequent readings. This allowed for the initial cake to form. The slope of the graph is measured and r is calculated from Eq. 12, in which P is the pressure, in grams per square centimeter; A is the area, in square centimeters; u is the viscosity of the filtrate, in poises; and c is the ratio of grams dry cake solids per grams of liquid in the sludge before filtration. This is taken to be equal to the weight of solid per volume of liquid where the density of the liquid is 1 g. per cubic centimeter. Hence, the units of c are in grams per cubic centimeter. It was assumed that the loss in weight on drying the sludge on a steam bath and then at 105° C. to constant weight gave the weight of liquid associated with the solids.

Example of calculation:

Time (min.)	θ (sec.)	V (ml.)	Corrected V*	$\frac{\theta}{V}$ (sec./ml.)
−2	—	0.0	—	—
0	0	1.5	0.0	—
1	60	2.8	1.3	46.3
2	120	3.8	2.3	52.3
3	180	4.6	3.1	58.0
4	240	5.5	4.0	60.0
5	300	6.1	4.6	65.2
6	360	6.7	5.2	69.4
7	420	7.3	5.8	72.5
8	480	7.8	6.3	76.2
9	540	8.4	6.9	78.3
10	600	8.9	7.4	81.0
12	720	9.8	8.3	86.7
14	840	10.7	9.2	91.3
16	960	11.5	10.0	96.0
18	1,080	12.3	10.8	100.0
20	1,200	13.0	11.5	104.2

Pressure of filtration, P = 10 lb./sq. in.
= 703 g./sq. cm.

Filtrate viscosity, u = 0.011 poise.

Solids content, c, $\frac{\text{g. solid}}{\text{ml. liquid}}$ = 0.075 g./ml.

Slope from plot of $\frac{\theta}{V}$ vs. V = 5.73 sec./cm.[6]

Filter area, A = 44.2 sq. cm.

$$r = \frac{2 \times 703 \times (44.2)^2 \times 5.73}{0.011 \times 0.075}$$

$$= 1.9 \times 10^{10} \text{ cm./g.}$$

* Total filtrate volume less volume at 0 sec.

Examination of Variables Affecting r

The first variable examined was the time required for carrying out the filtration test. A series of experiments was carried out in which samples from the same batch of sludge were filtered for periods of 20 min., 70 min., 20 hr., and 43.5 hr. The specific resistances obtained from the slope of each graph are given in Table II.

The agreement between the results is quite satisfactory, hence a standard filtration period of 20 min. was adopted for each experiment on untreated sludges. In the case of conditioned sludges which filter rapidly, readings were taken more frequently (for example, every one-half

TABLE II.—Specific Resistance at Various Test Times

Time	Slope	Specific Resistance
20 min.	2.76	2.3×10^{10}
70 min.	2.88	2.4×10^{10}
20 hr.	2.76	2.3×10^{10}
43.5 hr.	2.58	2.2×10^{10}

minute) for a shorter period. Easily filtered sludges were tested in the pressure filter, where an initial depth of sludge of up to 9 in. could be used.

Repeatability of Experiments

It was found from a large number of experiments, carried out in triplicate, that the values for specific resistance agreed within ±2 per cent.

Variation of Specific Resistance with Solids Content

Several tests were carried out to determine the effects of solids content on the value of specific resistance. Figure 4 shows the effect of dilution of a thickened digested sludge by tap water, supernatant liquor, and distilled water. It can be seen that a drop in specific resistance occurs which is outside experimental error. Carman's theory does not account for this drop, which may be due to variation in the state of peptization of the particles. The fall in specific resistance is not sufficiently great, however, to reduce the value of the results.

Effect of Pressure

As sludge is a compressible material, a series of tests was carried out to find out how specific resistance varied with pressure. Carman states that an empirical equation having the form $r_1 = rP^s$ expresses the variation of specific resistance with pressure. This equation may be put in the form log. $r = s$ log. $P + K$. If log. r is plotted

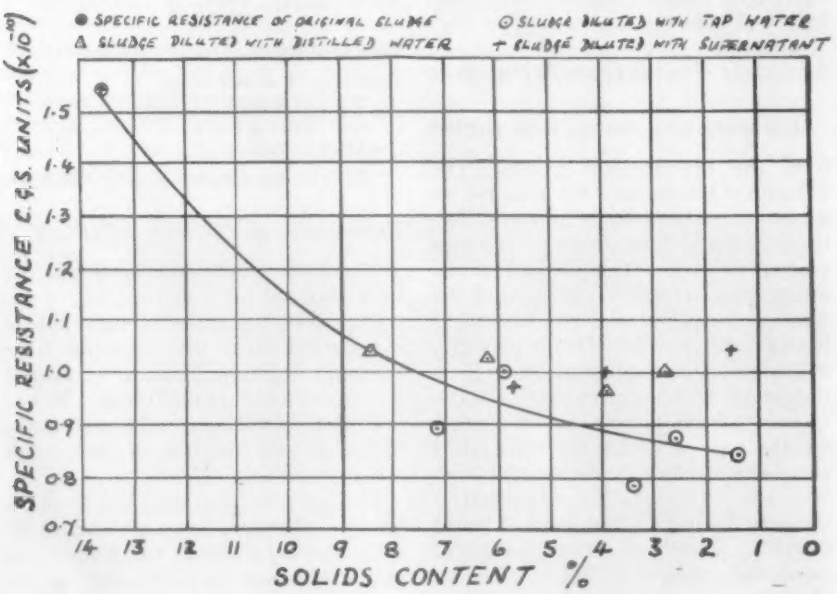

FIGURE 4.—Effect of dilution on specific resistance.

TABLE III.—Effect of Pressure on Specific Resistance

Pressure	Specific Resistance (cm./g.)
5	4.7×10^9
10	7.4×10^9
15	9.4×10^9
20	1.25×10^{10}
30	1.58×10^{10}
35	1.77×10^{10}
40	1.92×10^{10}
50	2.22×10^{10}
60	2.88×10^{10}

against log. P, a curve of slope s is obtained, where s is the coefficient of compressibility. When $s = 0$, $r = r_1$; that is, specific resistance is independent of pressure and the sludge is incompressible. The greater the value of s, the more compressible is the sludge. Table III gives the values of specific resistance obtained at various pressures for a sample of digested sludge. By plotting $\log_{10}$ (pressure) *versus* $\log_{10}$ (specific resistance), s is found to be 0.74.

Experiments on other samples of sludge have shown that the relation $r = r_1 P^s$ holds for all types of sludge. The following values have been found:

Type of Sludge	Range in Value of s
Digested	0.70 to 0.86
Activated	0.60 to 0.79
Raw	0.87*
Humus	0.80†

* Only one sample examined.
† Two samples examined.

Applicability of Carman's Theory

It can be seen from the results in the previous section that Carman's theory gives an exact measure of the filterability of a sample of sludge. To test its usefulness in evaluating laboratory results, a series of tests was carried out in which samples of digested sludge were treated in various ways and the filterability determined in terms of specific resistance. Tables IV and V and

TABLE IV.—Comparison of Aluminum Chlorohydrate and Ferric Chloride as Coagulants for Elutriated Digested Sludge

Treatment	Coagulant[1]	Specific Resistance	pH After Treatment
Before elutriation	0	1.6×10^{10}	8.3
Coagulant $FeCl_3$	4.4	1.6×10^9	7.5
	13.3	9.2×10^7	6.4
	22.2	4.7×10^7	4.2
	31.1	9.7×10^7	2.5
Elutriation	—	1.1×10^9	7.4
Elutriation and aluminium chlorohydrate	0.22	1.0×10^9	7.4
	0.86	1.2×10^8	7.3
	1.32	6.8×10^7	6.8
	2.20	2.1×10^7	6.7
	5.36	2.8×10^7	6.4
	8.60	4.4×10^7	5.8
Elutriation and ferric chloride	1.68	1.4×10^8	6.7
	4.21	7.2×10^7	5.8
	6.77	2.6×10^7	5.2
	9.30	2.7×10^7	4.2
	13.50	3.5×10^7	2.5

[1] As percentage of total sludge solids.

Figure 5 show the results of some of these experiments. It can be seen from these results that specific resistance indicates the efficiency of any treatment more accurately and effectively than does the time required for the cake to crack. Aluminum chlorohydrate is a new coagulant kindly supplied for ex-

TABLE V.—Comparison of Coagulation and Coagulation Plus Freezing and Thawing[1]

Coagulant[2]	Specific Resistance	
	Unfrozen	Frozen
0	3.6×10^{10}	1.9×10^{10}
0.29	1.5×10^{10}	7.4×10^9
0.58	6.8×10^9	2.3×10^7
0.87	1.7×10^9	$<2.0 \times 10^7$

[1] Coagulant: ferric chloride.
[2] As percentage of total sludge solids.

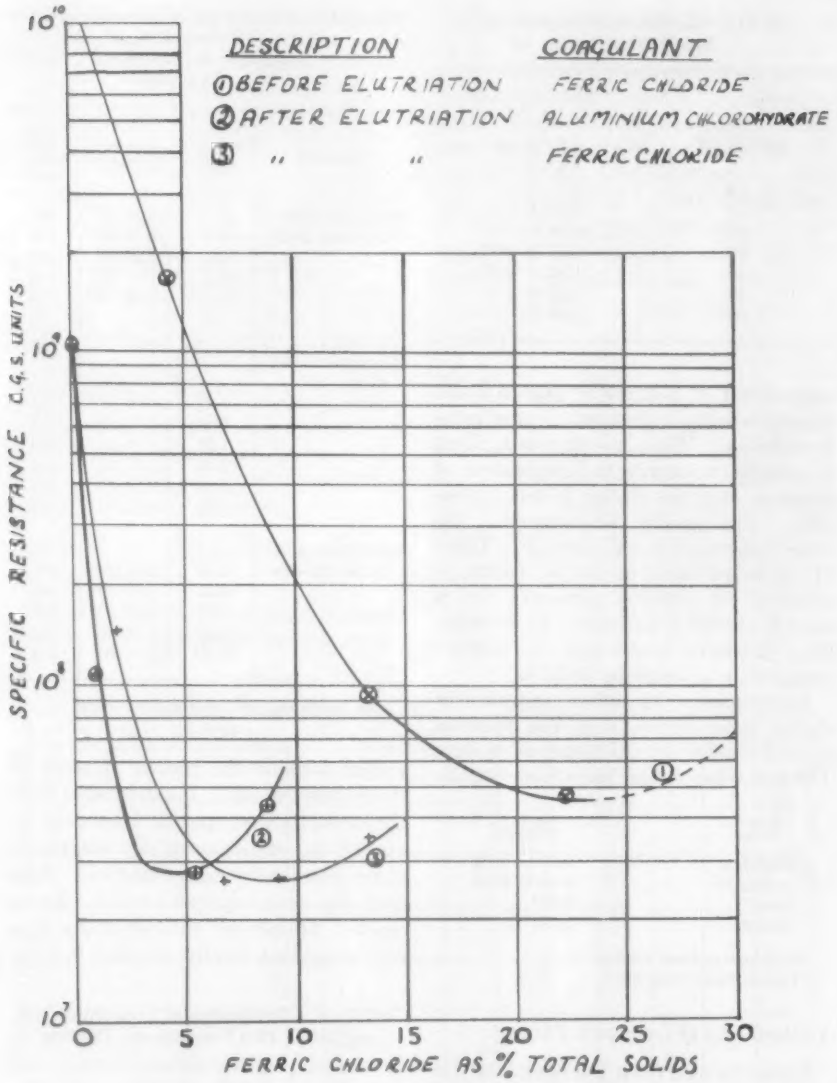

FIGURE 5.—Effect of coagulant on specific resistance.

periments by Messrs. Peter Spence & Co., Widnes. It has the approximate formula $Al_2Cl(OH)_5$ and consequently is more basic than Al_2Cl_6 or $FeCl_3$. This is indicated by the sludge pH after adding the coagulant. The results show that the minimum specific resistance obtained by using aluminum chlorohydrate is similar to that obtained for $FeCl_3$. The quantity of coagulant used to reach this minimum is, however, less in the case of aluminum chlorohydrate.

Conclusions

The results given in this paper indicate the utility of Carman's theory in expressing filtration results. Further results showing the usefulness of the concept of specific resistance in research work are given in a paper by Coackley (13) where specific resistance is used to show the effect of aerobic and anaerobic digestion on the filterability of samples of sludge.

Specific resistance is a useful parameter for expressing filtration results and it has a sound theoretical basis. Determination of specific resistance is simple and may be carried out with standard laboratory equipment. By measuring the specific resistance at various pressures up to atmospheric pressure, a value can be obtained for the compressibility which is not greatly different from that obtained over a larger range of pressures. If work is to be carried out on high-pressure presses it is recommended that a piece of apparatus similar to the one described herein and working up to 100 or 150 lb per sq. in. should be used for preliminary tests.

Summary

Various theories of filtration applicable to sewage sludges have been invesgated and Carman's theory appeared to be the most appropriate theory to use. Experiments have confirmed that Carman's theory and the concept of specific resistance adequately describe the results of filtration experiments and specific resistance is a suitable parameter to use in comparing the efficiency of different prefiltration treatments, coagulants, and for research purposes.

Acknowledgments

This paper is based on some of the work carried out by the authors on the dewatering and filtration of sewage sludges in the Chadwick Laboratory of the Department of Civil and Municipal Engineering, University College, University of London. Thanks are due the Chadwick Trustees for grants which initiated the research into the problem of sludge dewatering and to the Rockefeller Awards Committee of the Institution of Civil Engineers for research grants.

The authors also wish to acknowledge the interest and encouragement of Professor H. J. Collins and Mr. H. R. Oakley while carrying out the work.

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MEETINGS OF INTEREST

1956

Aug. 20–31 **Massachusetts Institute of Technology.** Disposal of Industrial Wastes by Biochemical Processing. Summer Session. M.I.T., Cambridge 39, Mass.

Aug. 22–24 **Hydraulics Division, American Society of Civil Engineers,** University of Wisconsin, Madison, Wis. Professor Arno T. Lenz, College of Engineering, University of Wisconsin, Madison 6, Wis.

Sep. 17–21 **International Instrumentation-Automation Conference and Exhibit,** New York, N. Y. Fred J. Tabery, 250 W. 57th St., New York, N. Y.

Sep. 23–26 **Public Works Congress and Equipment Show,** Fort Worth, Texas. American Public Works Association, 1313 E. 60th St., Chicago 37, Ill.

Oct. 8–11 **Federation of Sewage and Industrial Wastes Associations,** Hotel Statler, Los Angeles, Calif.

Oct. 8–12 **Bavarian Biological Institute, Munich, Germany.** Advance course in biology of sewage and stream sanitation. Dr. H. Liebmann, Bayerische Biologische Versuchsanstalt, Veterinarstrasse 13, Munich 22, Germany. Applications by Sept. 22.

Oct. 15–19 **American Society of Civil Engineers,** Annual Meeting, Pittsburgh, Pa.

Nov. 12–16 **American Public Health Association,** 84th Annual Meeting, Atlantic City, N. J.

Nov. 12–17 **Public Works and Municipal Services Congress and Exhibition,** Olympia, London, England. The Municipal Agency Ltd., 70 Victoria St., London, S. W. 1, Eng.

Nov. 19–20 **Sanitary Engineering Conference,** Kansas City Section, American Society of Civil Engineers, Continental Hotel, Kansas City, Mo. R. G. Kincaid, Chairman, P. O. Box 7088, Kansas City, Mo.

Nov. 27–30 **National Chemical Exposition,** Public Auditorium, Cleveland, Ohio. American Chemical Society, 1155 16th St., N. W., Washington, D. C.

CORRECTING STORM-WATER INFILTRATION, TONAWANDA, NEW YORK *

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Original Sanitary Sewer System

The town of Tonawanda, N. Y., lies north of and adjacent to the city of Buffalo. The westerly boundary is the Niagara River; and the northerly boundary, the city of Tonawanda and Tonawanda Creek, which is a part of the Erie Barge Canal system. A section of the central part of the town of Tonawanda adjacent to Buffalo, about two miles east and west and one mile north and south, constitutes the village of Kenmore. The town is about five miles wide and averages three miles in length, north and south. The topography is generally flat, with a small slope to the west and north. Part of Kenmore slopes toward Buffalo.

In the early 1920's suburban growth began first in Kenmore and later in the town of Tonawanda. The early Kenmore sanitary sewers discharged into Buffalo. Prior to 1925 there were few municipal sewers in the town of Tonawanda.

About 1925, Sanitary Sewer District No. 2 was organized to include approximately five square miles of area just north of Buffalo and Kenmore, which it was thought would be suitable for residential development. Sanitary sewers were planned for areas considered for immediate development, and trunk sewers were included to pick up the flow from these sewers and also the flow from the village of Kenmore. A sewage treatment plant was located on Two-Mile Creek to the north of the town of Tonawanda and almost one mile from the Niagara River. Gravity flow was possible to the treatment plant from all areas except a small area to the east served by the Highland Avenue lift station.

Trench excavations were in a heavy clay and only a small amount of rock was encountered. Cement mortar was considered an acceptable joint material for vitrified pipe construction, so it was used extensively. The manholes, unfortunately, were not well plastered on the outside.

Sewers were constructed either in the subdivision streets during early stages of construction or in platted street right-of-ways; consequently, house laterals were installed according to the plans of the developer. A considerable length of sewer was installed prior to the grading of the streets for pavements. Where this was the case, backfilling was permitted without tamping, the material being placed in the trench by a backfill machine or bulldozer, with the trenches trimmed after the first winter. Settlement due to rain and snow provided some compaction, but not equal to the precautions which are taken today.

In the late 1920's and early 1930's Sanitary Sewer District No. 3 was organized to include the easterly part of the town of Tonawanda, not included in District No. 2. The topography of the northerly part of this district was very low. Ellicott Creek ran through the northerly section and at high stage overflowed its banks and flooded as much as a mile from its normal banks in the lowest section. The trunk sewer leading to the sewage treatment plant,

* Presented at the 1956 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 18–20, 1956.

located on the north bank of Ellicott Creek, passed through this low area at considerable depth and then under Ellicott Creek. The sewage from this area was pumped to the sewage treatment plant.

The conditions of construction were much the same in this district as in District No. 2. In addition, some of the deep trunk sewers encountered a very unstable material, which, while clay, acted almost as a running sand. Adequate means were not taken in the construction of these sewers to assure permanent position. Subsequently, some of these sewers, when trenches were opened, were found to have been deflected from both line and grade.

When the creek flooded the low areas, water covered some of the manholes. In neither district were any storm sewers constructed simultaneously with the sanitary sewers. In both districts it was the general practice to drain turnpiked street ditches into the manholes of the sanitary sewers.

Since there were no storm drains, many houses drained roof water to the sanitary sewers, or if not roof water directly, the drain tile system around and under the building was connected. In most cases where the latter was done, all the roof water eventually reached the sanitary sewer, particularly if there were no down spouts, as the backfill material adjacent to the building wall was generally composed of building debris or porous material.

As long as the sanitary sewers and treatment plants were not over-loaded by the storm water flow, there was no particular concern either by householders or public officials. About 10 years after the facilities were constructed the population increased and the resulting sanitary sewage flow, together with the storm water, caused trouble during storm periods.

Early Storm-Sewer Construction

The early storm sewers were intended primarily to serve pavement drainage and were not large enough, nor sufficiently deep, to serve the built-up adjacent areas. The sewer depths were particularly shallow because the outfalls had to discharge into surface streams or ditches, which because of the flat topography were not much lower than the surfaces to be drained. Many of these storm drains were built by or taxed against subdivision developers, who could not afford the financial burden for adequate storm sewers. Furthermore, no over-all town drainage plan had been developed at that time.

Since these sewers were inadequate to handle the total storm flow during heavy rains, they would back up so that water stood on the streets for considerable periods of time. Where storm sewers had not been built the ventilated manhole covers in the sanitary sewers permitted large quantities of water to enter the sewers.

Population Increases

From the 1920's the town of Tonawanda became one of the fastest growing towns in New York State. The population increased to about 80,000 persons in 1955, with large supporting industries located along the Niagara River. Fine schools were built, shopping centers developed, major highways constructed, and other municipal services provided. These municipal improvements will continue to expand the population, which should level off between 100,000 and 125,000 persons.

Early Remedial Action

In the mid 1930's a program was set up to disconnect unused sanitary sewers from the sewer system, particularly those lines having lateral house service connections. Manholes subject to surface flooding were provided with solid covers, and in some cases these were sealed. Known diversion of storm water from ditches to the sanitary sewers was discontinued where possible. Furthermore, an ordinance was passed prohibiting new connections for the

purpose of discharging roof water to sanitary sewers. Efforts also were made to disconnect existing connections.

Sections of the sanitary sewers, known to be in bad condition, were recaulked under the various construction projects sponsored by the Federal government during the unemployment relief programs of the 1930's.

In addition, a section of the trunk sewer in District No. 3 was replaced by a new parallel sewer. Bypasses were installed at the two sewage plants to divert storm water. Extra pumping capacity was installed at some of the pumping stations. Finally, a postal-card canvass of the town of Tonawanda was made to ascertain the most critically flooded sections.

These measures, however, were not adequate to relieve private homes and commercial establishments from flooding. Serious financial loss occurred after every heavy storm, and frequently in the spring from melting snow.

The town officials then decided that the only way to eliminate the damage caused by flooding of the sanitary sewers was to plan and construct a town-wide storm drainage project. Engineering studies for the east side were authorized first, followed by reports for the village of Kenmore, and the west side of the town of Tonawanda.

Storm-Water Drainage Projects

East-Side Drainage Project

About 1945 the town of Tonawanda was ready to start constructing a comprehensive system of intercepting storm and overflow sewers in the eastern section where the population and need were greatest.

Studies had been made for a separate storm-water system, with no connection to the sanitary sewer, and also for a system of storm sewers deep enough to intercept the surcharged storm flow from the sanitary sewers. This latter plan was adopted as being less expensive for the results which might be accomplished. The sewers were planned to intercept the critically over-loaded points in the sanitary sewers and to connect to the existing storm sewer outlets. Provision has been made to provide points of discharge for future storm sewers which might be needed in areas to be developed or in developed areas where storm drainage had not been constructed.

In the heavily built-up areas, the sewers were designed for a five-year storm. These areas were largely in the southerly part of the town. In an intermediate area where houses were being planned with larger lots a three-year storm basis was used. In the northerly section where the land was very low, some consideration was being given to a municipal park. In another section, a golf course was proposed. Since there was a good possibility of a less dense population in this area, only a one-year storm basis was used for designing this section. Considerable money was saved through the use of these sliding design criteria.

The largest storm drains proposed were two cell, each cell 9 ft. wide by 7 ft. high. Other lines were 16 ft. wide by 7 ft. high. As the trunk drains extended upstream, the size decreased to about 48 in. in diameter, which was considered a minimum size for the trunk system.

The depth of the outlet sewers was controlled by the water level in Ellicott Creek, into which they discharged. The roof of the outlet conduits was placed 6 in. above known high water in the creek. The upstream sections were designed to accept the overflows from existing sewers.

The East-Side System had two main trunk sewers with various tributaries. The first construction contracts were let in 1948 for the Colvin Section. Sewer contracts totaled approximately $3,750,000 and attracted contractors from a considerable distance.

Due to finances, a part of the upper section of the system was omitted from

the initial construction awards to observe if what was to be built would be effective. After observing conditions in the sanitary sewers where there was still some flooding, the Brighton Road section was built in 1950 for about $350,000; and the Colvin Extension in 1954, for $113,000. This construction completed the system as originally planned.

The interception chambers were designed with side weir overflows from the sanitary sewers. The length of weir was sufficient to keep the increase in sewage depth at a minimum for a flow three times the dry weather flow. The sewer department has observed flow conditions and, in some cases, has found it necessary to adjust some of the weirs. Since the last section was built, there has been no flooding in the area.

The Parker Avenue Section was put under contract in 1952 at a cost of about $2,500,000. Most of the overflow and interception chambers were in the upper sections. The town officials realized that the work already let would not be sufficiently effective to protect an area where a large school and about 1,000 new houses were being constructed. Therefore, an additional contract was let in 1953 for $372,000 and two more in 1954, totaling $425,000. This construction has provided relief from flooding in the sanitary sewers and made available needed outlets for local storm sewers, many of which were built to serve the 1,000 home development.

The program had been estimated in the 1945 reports at $7,500,000. The total construction cost was $7,520,438, to which must be added engineering, legal and administrative charges. At the end of the construction in 1954 the project costs totaled about $8,200,000.

Kenmore Storm Drains

The east side of Kenmore had an arrangement to discharge a certain amount of storm drainage into the city of Buffalo sewers, administered by the Buffalo Sewer Authority. Some of the lateral sewers in this area were overloaded from storm water for reasons similar to those enumerated for the town of Tonawanda. A trunk relief system was considered to be the only effective remedy.

In the late 1940's an intercepting trunk system was designed to relieve many of the overloaded points in both the sanitary and storm sewer system. This flow was brought to a storm-water pumping station, the discharge from which flowed into the Buffalo sewers. The pumping capacity of 15 m.g.d. was limited by the contract with the city of Buffalo. In the interest of economy, the station was built with deep well-type pumps in a wet pit. The operation has been satisfactory and substantial relief afforded.

Later in the early 1950's, a similar station was built on the west side of Kenmore to discharge into a surface stream. Ultimately, when drains now under construction in the West-Side Drainage Project of the town of Tonawanda are completed, gravity flow to the town system will be possible, and the station can then be abandoned.

West-Side Town Drainage Project

A study similar to the one made for the East-Side Project was undertaken in 1948 for the west side of the town of Tonawanda. The financial conditions in the town, considering other substantial construction, made it necessary to delay consideration of this project until 1954. At that time preliminary plans were made for the proposed trunk intercepting sewer system. The construction was divided into two parts. The Two-Mile Creek trunk sewer was planned to serve the westerly section, including some industrial area, the southerly section, and would provide an outlet for the west side of the village of Kenmore system. The northerly section would be served by the Ensminger Road trunk.

The storm-drain sections are about the same size as those designed for the east side. Interception chambers are provided at critical points for relief of the sanitary sewers. The outfall discharges into Two-Mile Creek at a point about two miles from the Niagara River.

A contract was let for the larger size sewers in the Two-Mile Creek trunk sewer in 1955 for $1,425,000. The balance of the work on the Two-Mile Creek trunk sewer will include contracts totaling about $950,000. Other plans are being prepared for an estimated $1,200,000 worth of work on the Ensminger Road trunk sewer, which may not be let until 1957.

The total cost of the West-Side Town Drainage Project, including engineering, legal and administrative charges, will approximate $3,900,000. This does not include certain other sewers which are neded to connect the village of Kenmore outlet, the cost of which would be largely borne by Kenmore.

Construction Features

As has been previously stated, the larger storm drains were of reinforced concrete, rectangular in section, either one or two cell, and generally 7 ft. high with widths up to 16 ft.

The large cast-in-place sewers were designed for good foundation conditions; poor conditions required the use of piles. The downstream sections of both East-Side storm drains required piling. An intermediate section required a subbase foundation course.

Where the depth of excavation did not greatly exceed the height of the sewers, a dragline was used for making the excavation. In deeper cuts, partial excavation was made by dragline, and the deepest section was constructed with tight sheeting and bracing called "subway type" construction. All work was done in open cut, except crossings under railroads and main highways, where tunneling was used. The longest tunnel was about 100 ft.

The concreting was generally done in two pours. The base slab and sections of the vertical sidewalls about 14 in. high were included in the first pour. A considerable amount of this work was constructed ahead of the sidewall and roof pour. Collapsible forms were used as forming for the second pour. Since 60 ft. constituted one day's pour, the 200 ft. of available forms provided three days of work. The forms were moved ahead in sequence after each pour, so that the operation was never blocked. When the concrete had set sufficiently the forms were retracted for removal, and then pulled ahead. Some contractors used central mixing plants for concrete. Others used transit mix concrete. The interception chamber construction was generally a custom-formed job and was made after the main conduit had been completed.

The jacking operations for the 96-in. diameter pipe used by two contractors was particularly interesting. Various construction features of the projects received comment in publications serving the engineering field and the construction industry (1). Approximately 10,000 cu. yds. of rock excavation was necessary in one section.

Total Project Costs

When all sections of the town of Tonawanda and village of Kenmore drainage projects have been completed, the municipal officials feel that flooding conditions will not occur in the sanitary sewer systems and that adequate storm-water outlets for existing and future storm sewers will have been provided. The total cost to the town of Tonawanda will have been about $12,000,000 and for Kenmore more than $1,000,000 which makes a grand total of $13,000,000.

The Sanitary Sewer System

The present sanitary sewer system includes those sections of old construc-

tion in the older parts of the town of Tonawanda, and the newer sewers built in the recently built-up areas where all work has either been done by the town directly, or to its specifications and under its own inspection.

The specifications call for bitumastic joints, with vitrified tile pipe lengths of 3 and 4 ft. Concrete cradles are used in deep sections, and special foundation provisions are provided in any unstable soil. In all streets where settlement of trenches is important, either selected material is used for backfill, or care is taken to consolidate the replaced excavated material. Infiltration tests are made on new construction and efforts made to reduce this to a minimum. The cost of sewers is somewhat higher under such specifications, but results are deemed to be worth the money.

Consequently, the present sanitary sewer system on a total length basis has much less infiltration. The points of relief to the interceptor storm sewers prevent flooding of the sanitary sewers. It has been unnecessary to replace the original sanitary sewer construction, which because of locations under pavements and proximity to other utilities would have been very expensive. The town of Tonawanda, therefore, now has a sanitary sewer system with minimum infiltration in the new sections and controlled infiltration in the older sections.

Reference

1. *Concrete Highways*, Winter (1949).

NATIONAL SCIENCE FOUNDATION POSTDOCTORAL FELLOWSHIPS

As a means of promoting the progress of science, the National Science Foundation plans to award a limited number of postdoctoral fellowships on October 16, 1956. These fellowships are in addition to those awarded by the Foundation in March of each year.

Individuals holding a doctoral degree, or having equivalent research training and experience in the fields of mathematics, physics, medicine, biology, engineering and other sciences, are eligible for the fellowships. Annual stipends will normally be $3,400 per year. Provision is made for the payment of tuition and fees, dependency allowances ($350 for each dependent) for married Fellows, and limited travel allowances.

Application materials may be obtained from the Fellowship Office, National Academy of Sciences, National Research Council, 2101 Constitution Ave., N. W., Washington 25, D. C.

STUDIES ON THE OXIDATION KINETICS OF BIOLOGICAL SLUDGES *

By W. Wesley Eckenfelder, Jr.

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In biological oxidation processes sludge is produced from the synthesis of organic matter removed in the system as an integral part of the treatment process, and the sludge undergoes auto-oxidation and mineralization. The sludge consists of microbial protoplasm in various phases of growth, non-oxidizable organic matter, stored organics in the microbial cell and inorganic solids removed during the solid-liquid separation step in the bio-oxidation process. In conventional processes the sludge accumulates and must be disposed of.

Character of Biological Sludge

Sludge from bio-oxidation processes consists of living protoplasm, mineral cell constituents and amorphous matter. The principal chemical constituents are carbon, hydrogen, oxygen and nitrogen with lesser amounts of phosphorous, sulfur and trace elements. Hoover and Porges (1) showed sludge synthesized from dairy wastes had the empirical formula $C_5H_7NO_2$. This sludge contains 12.3 per cent nitrogen and theoretically requires 1.42 g. oxygen for each gram of sludge completely oxidized. Laboratory studies revealed an oxygen equivalency of 1.36 g. of oxygen per gram of sludge on a volatile solids basis. In studies of other industrial wastes, Helmers *et al.* (2) produced a sludge with the general formula $C_7H_{11}NO_3$ containing 8.9 per cent nitrogen and requiring 1.53 g. of oxygen for each gram of sludge oxidized. Variations in the empirical composition will depend on quantity and availability of nitrogen and phosphorous in addition to other microbiological variables. Studies on several sludges synthesized from various industrial wastes revealed a range of 1.36 to 1.44 g. of oxygen per gram of sludge volatile solids oxidized (3).

The volatile content of activated sludges will depend upon the percentage of inert and non-oxidizable volatile solids accumulated in the system, in addition to the growth phase of the microbial culture. Pure microbial cultures undergoing active growth will be 90 to 94 per cent volatile (4). As oxidation under starvation conditions progresses, this volatile content will decrease due to the mineralization of cellular constituents. Using synthesized milk waste, Hoover (1) produced a sludge of 92 per cent volatile content. Sludges synthesized from cotton kiering, rag rope and brewery waste showed a variability of content of 72 to 89 per cent (2). Sludge from pulp and paper waste oxidation was 85 per cent volatile (5). Most domestic sewage sludges are 75 to 90 per cent volatile.

The volatile solids content is not necessarily indicative of the active fraction of microorganisms present in the sludge. The active fraction, in this instance, is defined as the fraction of microbial sludge related to the total weight of volatile sludge. For example, in the pulp and paper sludge cited above, while the volatile content was 85 per cent, the active sludge frac-

* Presented at the Annual Meeting of the New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 18–20, 1956.

tion as determined by system material balances was only 70 per cent. This difference can be attributed to the accumulation of fiber, lignin and cellulose of low oxidation rate in the system.

The heat content of activated sludges from industrial waste oxidations have been shown to be 10,321 B.t.u. per pound for dairy waste sludge (6), and 9,872 B.t.u. per pound for pulp and paper waste sludge. These values compare to the value for domestic sewage activated sludge of 10,000 B.t.u. per pound as found by Fair (7). The sludge age appeared to have only a minor influence on the heat content.

Sludge Growth

Sludge growth can be related to the B.O.D. removal in the process, the quantity of active solids under aeration, the nature of the waste being treated and the quantity of available supplementary nutrients. Most investigators have found that approximately 1 lb. of volatile sludge solids is produced for each 2 lb. of B.O.D. removed. Based on pure compounds oxidized by activated sludge, conversion to sludge varied from 44 to 64 per cent for glucose (8) to 65 to 85 per cent for carbohydrate (9). Under specific operating conditions, the biological volatile solids accumulation can be expressed for any system by the general equation:

Pounds volatile biological solids per day = a (lb. B.O.D. removed/day) − b (lb. mixed liquor volatile suspended solids).

The value of constant a, representative of the fraction of B.O.D. removed which is synthesized to sludge, generally will vary between 0.4 and 0.75. After 24 hr. of aeration the fraction synthesized for various organic compounds varied from 43 to 93 per cent (8).

Data on sludge accumulation are summarized in Table I. Sludge growth from a pulp and paper waste oxidation in which no preseeding was used is shown in Figure 1. The B.O.D. loading applied to the system was regulated to 0.3 lb. B.O.D. per pound of mixed liquor suspended solids per day.

TABLE I.—Sludge Growth Constants for Various Wastes

Source	Sludge Growth Constant, a	Temperature (°C.)	Reference
Pharmaceutical waste	0.77	25	(10)
Sewage	0.49	20	(11)
Sewage	0.64	12	(12)
Cotton kiering waste	0.44	20	(2)
Rag rope waste	0.37	10–30	(2)
Brewery waste	0.33	10–30	(2)
Brewery waste	0.56	20	(13)
Pulp and paper waste	0.76	30	(5)

Sludge Oxidation

Biological sludge can undergo oxidation of its own cellular tissue. This has been defined as endogenous respiration: in the absence of available nutrients, cells oxidize their own tissue slowly in order to obtain energy for maintenance. Recent investigations have shown that endogenous respira-

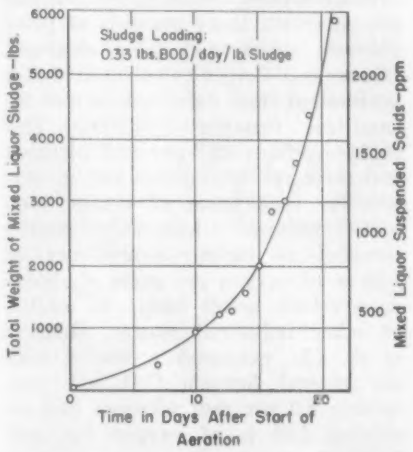

FIGURE 1.—Sludge growth at constant ratio of B.O.D. to sludge loading; pulp and paper waste.

tion also occurs concurrently with synthesis. The utilization rate for endogenous respiration will generally vary from 5 to 10 per cent of the rate for active metabolism.

During the early phase of endogenous respiration, the rate equation may approximate monomolecular kinetics and the rate of sludge oxidation may be expressed as per cent per day of the sludge solids under aeration. With continuing aeration, the rate falls off due to the oxidation of more stable components. This rate of decrease of oxidation is logarithmic in nature.

Typical oxidation curves for various systems are shown in Figure 2. As the oxidation proceeds, cellular nitrogen is broken down and released to solution in the form of ammonia. Under continuous oxidation this ammonia is further oxidized to nitrates.

The rate of endogenous respiration and sludge oxidation may at any time be related to the sludge age, or to the mean length of time the sludge has been undergoing aeration. The sludge age is in turn related to the B.O.D. and suspended solids loading to the process.

It may be anticipated that the rate of sludge oxidation will vary inversely with sludge age. With high sludge age (indicative of low organic loading and prolonged aeration), a large percentage of the sludge oxidation occurs in and through the aeration tanks. Further separate sludge oxidation will occur at a lower rate than that characteristic of high-rate processes. With high organic loadings and low sludge ages, only a small portion of the synthesized sludge is oxidized in the aeration tanks and subsequent sludge oxidation will yield higher rates.

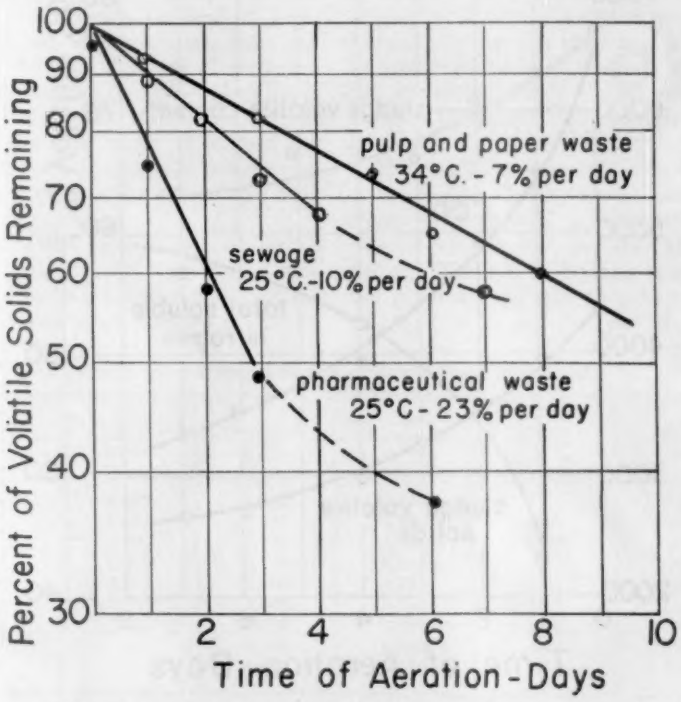

FIGURE 2.—Reduction of volatile sludge solids with aeration.

Observed oxidation rates also will vary with temperature and with the nature of the waste being treated.

Experimental Studies

Thickened sludge obtained from the recycle system of bio-oxidation waste treatment plants was used as a source of sludge for the oxidation studies reported here. This sludge was aerated in 4-l. containers, and daily samples were withdrawn for determination of suspended and volatile solids, soluble nitrogen, C.O.D. and B.O.D. and for oxygen utilization rate measurement. A polarograph was employed for oxygen utilization rate measurement. Daily evaporative losses were made up with distilled water.

TABLE II.—Domestic Sewage Activated Sludge*

Aeration Period (days)	C.O.D. (p.p.m.)	Suspended Solids (p.p.m.)	Volatile (%)	Soluble Nitrogen (p.p.m.)
0	6,600	4,380	76.5	—
1	5,500	3,950	73.0	46.0
2	4,950	—	71.0	—
3	4,250	3,250	66.0	—
4	3,950	3,000	67.0	86.0
5	3,800	—	66.5	—
6	—	—	—	—
7	3,400	2,700	63.5	94.0

* Temperature is 25°C.

Domestic Sewage

Studies on the endogenous respiration and oxidation of domestic sewage activated sludge have been conducted by several investigators. Sawyer (8)

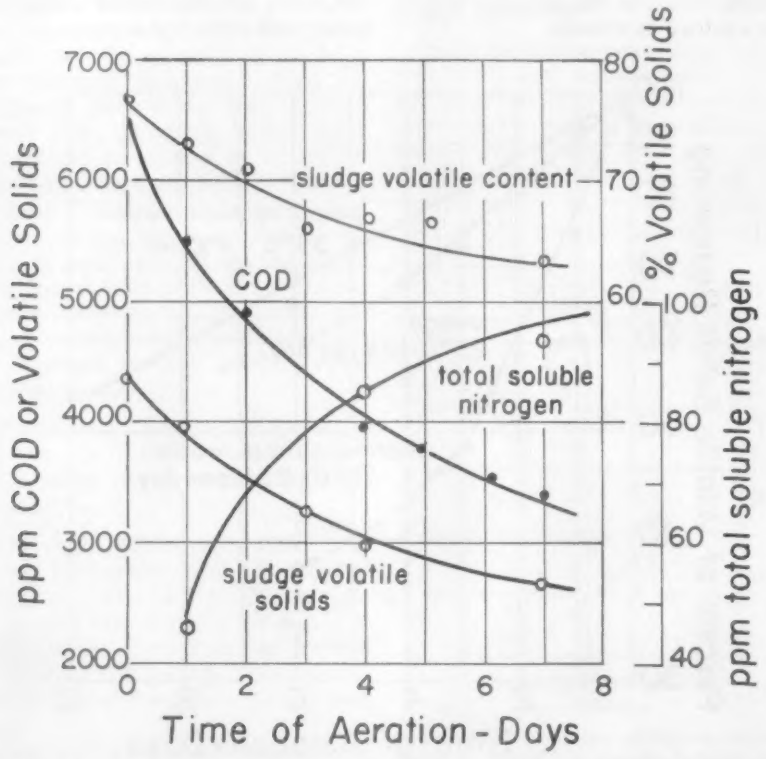

FIGURE 3.—Endogenous respiration trends; domestic sewage activated sludge.

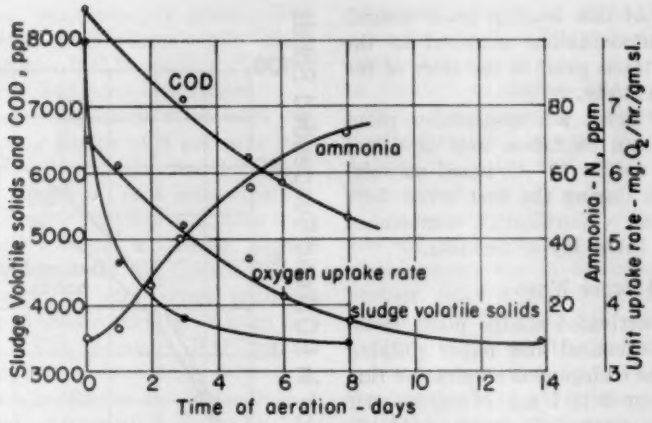

FIGURE 4.—Endogenous respiration trends; pulp and paper waste activated sludge.

showed a variation in endogenous respiration of 1.85 to 9.8 mg. of oxygen per hour per gram of sludge undergoing aeration for 24 hr. with no nutrient addition. Placak and Ruchhoft (9) reported various activated sludges to have endogenous respiration rates of 2 to 6 mg. of oxygen per hour per gram of sludge. The rate of activated sludge oxidation from pilot-plant studies at Ridgewood, N. J., at 20° C. varied from 3 to 7 mg. of oxygen per hour per gram of sludge, depending on the length of time the sludge had been undergoing aeration.

In oxidation rate studies of sludge from a conventional activated sludge plant, 10 to 12 per cent per day of the volatile solids were oxidized at 25° C. During a period of six days aeration, the volatile content of the sludge was reduced from 78 per cent to 64 per cent. After five days of aeration, first order kinetics were no longer approximated and the oxidation rate decreased rapidly with time. Nitrogen was solubilized, during the oxidation process, in approximate stoichiometric ratio to the sludge oxidized. These data are detailed on Table II and illustrated on Figure 3.

The results of four oxidation studies at the Bergen County Sewer Authority Plant (14) revealed a mean oxidation rate of 5.2 per cent per day at 21 to 24° C. The B.O.D. loading applied to the plant during this period averaged 0.2 lb. B.O.D. per day per pound of

TABLE III.—Activated Sludge—Pulp and Paper Mill Waste*

Aeration Period (days)	C.O.D. (p.p.m.)	Suspended Solids (p.p.m.)	Volatile Suspended Solids (p.p.m.)	Oxygen Uptake (p.p.m./hr.)	NH_3-N (p.p.m.)
0	8,520	7,642	6,434	61.8	11.1
1	8,680	7,416	6,160	33.5	13.5
2	6,440	5,921	4,940	26.0	28.6
3	7,120	6,195	5,320	22.6	40.5
5	6,240	5,690	4,790	12.0	56.0
6	5,920	4,940	4,140	19.8	—
8	5,330	4,780	3,840	16.7	72.5
9	—	4,630	3,890	16.4	—
14	—	4,150	3,550	—	—

* Temperature is 32°C.

sludge. At this loading level, considerable autooxidation occurred in the aeration tanks prior to the start of the oxidation study.

Sludge from a step-aeration plant exhibited an oxidation rate of 8 per cent per day at 19° C. based on volatile solids during the first seven days of aeration. Nitrification commenced after the third day of aeration.

Pulp and Paper Wastes

In an activated sludge plant treating semi-chemical and paper pulping wastes, the endogenous respiration rate varied from 3 to 7 mg. of oxygen per hour per gram of sludge (volatile solids basis) during a 10-hr. aeration period at 32° C. The B.O.D. loading averaged 0.4 lb. per day per pound of sludge. When sludge from this process was aerated, 7 per cent per day of the volatile solids was destroyed by oxidation. The ratio of oxygen consumed to volatile solids destroyed was 1.57. These data are shown in Figure 4 and Table III.

In studies on sludge oxidation from kraft mill wastes, Gehm (15) found a mean endogenous respiration rate of 2.1 mg. of oxygen per hour per gram of volatile suspended solids. In aerating a 1 per cent sludge, a reduction in B.O.D. of 82 per cent was found after five days of aeration.

Pharmaceutical Wastes

Oxidation studies were conducted on activated sludge obtained from pharmaceutical waste oxidation. These data showed that a 55 to 60 per cent reduction in sludge solids, and a 60 to 85 per cent reduction in B.O.D., can be attained in a five-to-six-day aeration period. The rate of volatile suspended solids reduction was approximately 25 per cent per day over the first three days of aeration at 25° C. The corresponding endogenous respiration rate of volatile solids was 14 mg.

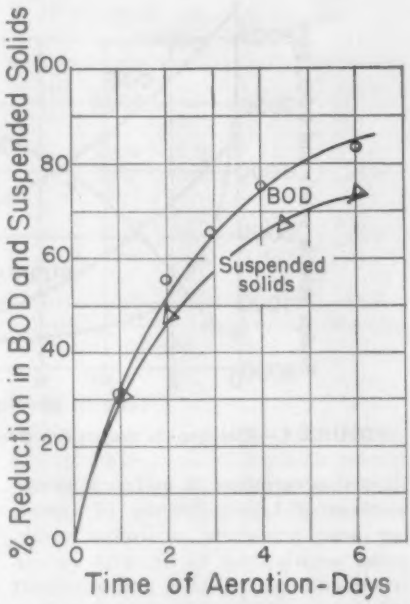

FIGURE 5.—Endogenous respiration trends; pharmaceutical waste activated sludge.

TABLE IV.—Activated Sludge—Pharmaceutical Wastes*

Aeration Period (days)	C.O.D. (p.p.m.)	Suspended Solids (p.p.m.)	Volatile Suspended Solids (p.p.m.)	B.O.D. (p.p.m.)	Oxygen Uptake (p.p.m./hr.)
0	5,960	4,408	3,784	1,550	—
1	4,300	3,152	3,008	1,020	42
2	3,160	2,216	2,144	618	30
3	2,840	1,872	1,808	533	21
4	2,680	1,760	1,440	431	12
5	2,000	1,360	1,168	—	12
6	2,000	1,280	1,080	—	—

* Temperature is 25°C.

of oxygen per hour per gram. This sludge was obtained from a pilot plant operating at a B.O.D. loading of 2 to 3 lb. per day per pound of sludge.

The same oxidation rates were obtained using sludge at 2 per cent concentration (dry weight basis) as were found at an 0.4 per cent concentration, thus indicating that concentration over this range was not a limiting factor. A high power level was maintained in the system by employing multiple turbines to insure adequate sludge dispersion. The average B.O.D. and solids reduction data from four runs are shown in Figure 5. Data from a typical run are shown in Table IV.

Dairy Wastes

The oxidation of sludges from dairy waste oxidation has been studied by Hoover (1) and Kountz (16). Hoover found a sludge oxidation rate of 24 per cent per day at 20° C. Similar results were reported by Kountz in pilot-plant studies.

Discussion

Sludge accumulated in bio-oxidation systems will undergo oxidation at varying rates depending upon the factors of temperature, waste characteristics, microbial content and sludge age. The oxidation rate approximately doubles for each 10° rise in temperature (12). The microbial content of sludges will vary widely depending upon the nature of the wastes being treated. For example, while dairy and cannery wastes are composed almost entirely of microorganisms, sludges from pulp and paper mill waste oxidation may vary from 50 to 75 per cent microbial content. This range is attributed to the variable quantity of fibre, pulp, etc. present in the raw waste.

The oxidation rate approximates monomolecular kinetics during the early phases of the oxidation process. With increasing times of aeration, the rate progressively decreases and approaches a limit of about 40 to 60 per cent volatile solids reduction. The remaining constituents are resistant to further oxidation and provide a residue for disposal. By comparison, most anaerobic processes provide a reduction in volatile content of about 60 per cent.

The quantity of accumulated sludge and the oxidation rate are a function of the sludge age in the bio-oxidation process, since a portion of the sludge synthesized from B.O.D. removal is oxidized in the aeration system.

For example, in a conventional waste treatment plant at a loading of 0.2 lb. B.O.D. per day per pound of sludge and a mean sludge oxidation rate of 8 per cent per day, as much as 80 per cent of the sludge synthesized may be oxidized in the aeration tanks. By comparison, in the pharmaceutical waste oxidation previously cited only 10 per cent of the sludge synthesized is oxidized at a loading level of 4.8 lb. B.O.D. per day per pound of sludge.

Sludge disposal by oxidation (endogenous respiration) has been employed in dairy waste treatment as reported by Kountz (16). Studies on other waste oxidation systems have indicated the feasibility of this method for sludge treatment. In most cases studied, the residue is non-putrescible and produces no odors. Pressure flotation can be employed for sludge thickening; concentrations of 2 to 3 per cent on a dry weight basis has been attained by this method. Nutrient chemical recovery, by recycling the nitrogen rich liquor after oxidation, may be advantageous in systems requiring supplementary nutrient addition.

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COME, NO MATTER HOW!

Interest in group trips to the Los Angeles Meeting, October 8–11, is being evidenced at Member Association meetings as the date for the Federation Annual Meeting approaches. Recent comment at the Ohio and Central States meetings indicates interest in those areas. Previously New York and more recently New Jersey (THIS JOURNAL, **28**, 7, 871; July, 1956) have expressed interest in train or plane group accommodations to California.

From east of the Mississippi River there are several train routes to the West Coast. Perhaps the three best-known U. S. routes are the Northern Route, the Central Route, and the Southern Route. Any travel agent or railroad office will be pleased to discuss your own wishes. It is possible to go one way and return another, thus seeing a great deal of the United States and possibly Canada. Many excellent stopovers and side trips are available at little additional cost.

Whether you travel by train, plane, bus, automobile, horseback, covered wagon, bicycle or steamship through the Canal, or around Cape Horn, be certain to come to the Los Angeles Meeting!

SEWER ODOR STUDIES *

By George W. Reid and Charles Imel

Respectively, Associate Professor and Student, Engineering College, University of Oklahoma, Oklahoma City, Okla.

The University of Oklahoma was requested to assist Oklahoma City in a study of odors associated with its sanitary sewer system. A cooperative arrangement was made between the Civil Engineering School of the University and the City Engineer by which students were employed, under the technical direction of the Professor of Sanitary Engineering, to conduct the studies. This informal arrangement is mentioned because other cities with like problems might be interested in arranging similar cooperative programs with a neighboring university.

This discussion is a progress report because both sewer and laboratory studies are still underway.

Cause of Odors

Sewer odors result from environmental conditions in a sewer that permit the anaerobic bacterial, and possibly fungal, decomposition of the free floating and deposited organic materials and subsequent dispersal of the gases produced. The production of odorous compounds in partially filled sewers with proper ventilation is believed caused by the submerged deposits of organic silts, greases, and slimes. Sewers flowing full or partially full but poorly ventilated often produce odors. There is some question as to whether or not the grease and the slimes simply form a matrix for the silts or are actually involved in odor production. The nitrogenous compounds decompose first, followed by organic sulfur and the sulfates. The principal odorous compounds produced are cadaverine, indole, skatal, mercaptans and hydrogen sulfide. Considerable work has been done by Pomeroy and Bowlus (1), Heukelekian (2), and others on reduction of organic sulfur and sulfates to form hydrogen sulfide. Generally, organic sulfur compounds produce hydrogen sulfide before the sulfates, in that the degree of anaerobiosis is greater in the latter. (Oxidation-reduction potential is lower.) The rate of production of sulfides and consequent odors is accelerated by an increase in temperature and B.O.D. of the sewage. Normal sulfate concentration apparently does not cause an odor increase but wastes containing high sulfates would. Although sulfides are produced in a pH range from 6.0 to 9.0, increases in pH reduce the proportion of hydrogen sulfide. For example at pH 6.0, 83 per cent of the dissolved sulfide is present as hydrogen sulfide, at pH 7.0, 33 per cent and at pH 8.0, only 5 per cent. It should be noted also that bacteria of the genus *Thiobacillus* can rapidly oxidize hydrogen sulfide from the sewer atmosphere to form sulfuric acid. The lower oxidation-reduction potential (Redox) required for sulfide production accounts for the observation that with ordinary velocities, the flowing sewage does not produce hydrogen sulfide in the usual time required for the sewage to reach the treatment plant.

The greater attention given to sulfides as opposed to other odorous compounds is in all probability due to their corrosiveness. Odors from the re-

* Presented at 29th Annual Oklahoma Water and Sewage Short Course; Stillwater, Okla.; Dec. 12–16, 1955.

duction of proteins to the amines or ptomaines (cadaverine, indole, and skatal) will develop from the organic deposits and from the flowing sewage as soon as it becomes septic. Furthermore, because of the higher Redox potential prior to hydrogen sulfide development, sewers may have odors even though hydrogen sulfide is not present.

Location of Points of Concentration

Sewers flowing full, or nearly full, on flat grades present the most likely conditions for odor production from deposits and flowing sewage. These conditions also are most suitable for the conversion of hydrogen sulfide to sulfuric acid and the liberation of gas at ventilated manholes. Therefore, the initial studies were designed to locate hydraulically the "points of concentration" of sewage, or the points in the Oklahoma City sewer system where these conditions would most likely occur.

Realizing that odors are generally associated with overload sewer conditions, a study was made of four trunk sewers, comparing their tributary area in terms of population served and coincident sewer capacity at all intervening points. A dimensionless constant $(A_c)/d^2$ was developed to indicate where sewer overloadings were most likely to occur. The constant was developed as follows:

1. Sewer capacity—
   $Q = AV$, let V remain constant (assume minimum flow).
   Then Q is proportional to A and consequently to d^2.
2. Quantity of sewage—
   Assuming an average per capita flow and an average residential population density.
   Then Q, the tributary area, is proportional to A_c expressed in terms of acres.
3. Relate the quantity of sewage to the sewer capacity.
   Then A_c/d^2 = relative concentration of sewage at points in any given type of sewer.

The mathematically determined points of sewer overload correlated rather well with observed points of high odor conditions. In one trunk line, the values of A_c/d^2 ranged from 0.54 to 6.95; the higher values occurred where there was greater odor production.

Methods of Odor Control

There are numerous methods of controlling sewer odors and many of them have been studied in considerable detail. In general, they include:

1. Methods directed at the removal of the slimes, grease, and silt deposits, such as mechanical cleaning, chemical cleaning with acid, caustics, or chlorinated benzenes, and finally, the addition of massive dosages of specific biological cultures designed to utilize grease in the sewer environment.
2. Methods directed toward the oxidation of reduced compounds (sulfides, for example) or increases in the oxidation-reduction potential of the sewage, including aeration, chlorination, use of sodium nitrate, sodium chlorate, or ozone.
3. Methods used to precipitate sulfides such as the addition of iron salts, zinc, or copper.
4. Methods to reduce the amount of free gases by increasing the pH such as the use of lime.
5. Reduction of B.O.D. and sulfate concentration by dilution or pretreatment of the wastes.
6. Use of specific toxic substances to halt bacterial action, such as chlorine, chloroben, zinc, copper, chloropropane, trichlorophenol, pentrachlorophenate or chromium.

Oklahoma City Studies

To date the Oklahoma City studies have been divided into two phases:

1. Empirical dosages of odor control materials and observations on selected sections of sewers known to produce odors.

2. Laboratory studies on two phases of the odor production problem; one related to the flowing sewage and the other to the slime, organic silt and grease matrix.

The three methods of odor control selected for study were chosen primarily because they were currently receiving attention. Selected methods were: (a) use of a biological additive, (b) use of chloroben, and (c) use of alkaline chlorination. Chlorine in alkaline solution was proposed as an economical use of chlorine in which the chlorine is released only as would be required to treat odors.

Biological Additives

Since the prevailing environment determines the type of bacterial activity present, the more conventional approach to the odor problem has been to clean the sewers mechanically, or render the bacterial life ineffective by the use of chemicals. Both processes are expensive. More recently considerable interest has been evidenced in the creation of more favorable conditions by massive inoculation with a bacterial culture that will utilize the deposited organic material and grease as food, and thus clear the sewer walls of decomposable solids. Inoculation merely accelerates the eventual determinative growth.

In these studies, a proprietary product* containing specific groups of facultative and aerobic bacteria, as well as fungal groups, was introduced into the sewer. The objective was to increase suddenly the rate of decomposition of organic deposits, causing them to slough off, thus improving the flow conditions and providing fresher sewage with a higher oxygen-reduction potential.

*"Bionetics" manufactured by the Reliance Chemical Company, Houston, Texas.

Evaluating Techniques

The tests chosen to reflect the environmental conditions of the sewer were principally to detect changes in grease, B.O.D., bacterial population and solids. These changes were the basis of the claim that the product was effective. Odor determinations were also made.

Several different specific tests for sulfur odor production were made but results were too erratic to be useful. Oxygen-reduction potential apparatus was not available. As both nitrogenous and sulfur compounds were implicated in odor production, it was believed that conventional tests depicting environmental conditions were superior to a search for reduced products.

Application of Additives

In order to bring the bacteria up to a highly active state, a 5-gal. sample of sewage was inoculated with 5 lb. of the biological additive and allowed to stand for 5 hr. before dumping it into the sewer. The application was made at the beginning of the period of minimum flow or about 1:00 AM on a Monday.

Sewer Tests

To determine the most effective method of application and sampling, three separate experiments were made on a representative sewer carrying sewage at the rate of 0.5 m.g.d.

In the first test, a section of the sewer which had no branch connection for about 2,000 ft. was used. Samples were taken at 7:00 AM on each of 10 days from a point at the lower end of this sewer to determine general variations in sewage conditions. After the initial application of 5 lb. of additive, samples were taken above and below the point of application at 7:00 AM each day allowing the sewage a travel time from the application point to the downstream sampling point of about 15 min. After one week, a second application of 2 lb. was made and sam-

TABLE I.—Effect of Biological Additive on the B.O.D., Settleable Solids, Grease and Bacterial Count, First Test

Date (1955)	B.O.D. (p.p.m.)		Grease (p.p.m.)		Settleable Solids (p.p.m.)		pH		Plate Count	
	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Upstream	Down-stream
March										
30[1]	120	—	—	—	450	—	7.6	—	—	—
30	270	—	—	—	450	—	7.6	—	1,200,000	—
31	480	—	64.1	—	9,000	—	7.6	—	—	—
April										—
1	480	—	95.3	—	21,000	—	7.45	—	—	—
2	90	—	59.6	—	3,000	—	7.6	—	200,000	—
3	276	—	30.0	—	600	—	7.6	—	—	—
4[1]	390	—	61.0	—	5,000	—	7.2	—	—	—
4	300	—	35.9	—	1,500	—	7.55	—	—	—
5	270	—	49.6	—	1,500	—	7.64	—	690,000	—
6	255	—	56.6	—	2,500	—	7.65	—	—	—
7	210	—	44.2	—	500	—	7.45	—	202,000	—
8	300	—	38.0	—	1,000	—	7.55	—	—	—
9	200	—	40.3	—	400	—	7.6	—	111,800	—
10	315	—	38.5	—	1,500	—	7.65	—	—	—
11[2]	205	—	63.6	—	4,500	—	7.3	—	—	—
11[3]	180	195	—	52.8	3,000	4,000	7.4	7.45	—	—
11	180	155	32.6	29.0	3,000	3,000	7.75	7.65	—	—
12	320	140	79.6	36.7	14,500	4,000	7.6	7.55	734,400	1,720,000
13	235	227.5	89.8	56.6	4,000	7,000	7.55	7.30	—	—
14	155	100	47.0	44.2	1,000	1,800	7.4	7.8	77,000	—
15	245	165	—	—	5,000	500	7.6	7.55	—	—
16	220	150	46.1	55.4	1,500	2,000	7.8	7.73	577,500	270,000
17	200	190	40.7	41.8	0	0	7.65	7.50	—	—
18[4]	330	250	97.8	103.7	9,000	3,000	7.25	7.11	—	—
18	260	170	67.3	50.3	700	1,100	7.6	7.55	—	—
19	280	260	44.5	78.0	2,000	1,000	7.55	7.65	1,370,000	1,010,000
20	140	200	34.4	36.7	1,000	1,500	7.50	7.55	—	—
21	426	90	109.3	33.4	7,500	2,000	7.4	7.45	—	—
22	309	272.3	38.0	74.2	6,000	6,000	7.35	7.50	—	—
23	430	345	107.7	129.4	22,000	10,000	7.40	7.40	1,680,000	1,400,000
24	220	160	1.4	29.1	3,000	1,500	7.5	7.6	—	—

[1] 1 AM.
[2] Additive added (5 lb.) 1 AM.
[3] 3 AM.
[4] Additive added (2.5 lb.) 1 AM.

pling continued for another week. The results of the tests (Table I) indicated such alteration of the biological environment that more extensive analysis using a longer contact period seemed desirable. The difference between the upstream and downstream results showed a decrease in B.O.D., and an average decrease in grease and solids. The bacterial plate count showed a very high initial reading.

In the second test, application was made farther up the sewer to allow the sewage more travel time before sampling began. Four applications were made simultaneously at four different points in two major branches of the main outfall. An application of 10 lb. was made at the upper end of one major branch, allowing a flow time to the point of sampling of about 2 hr. Two smaller applications of 5 lb. each were made in this same branch, allowing a flow time of 1 hr. to the point of sampling. The other major branch line was treated at a lift station and

the flow time from this station to the sampling point was about 1 hr.

Samples were taken at the downstream point used in the first experiment at 7:00 AM each day for one week, then every other morning until the sewage began to show a normal condition. Considerable rain fell during this period.

Table II shows the effect of the additive. The normal values shown are the average of 25 samples taken before and after this experiment.

The third test was an attempt to determine the consistency of the immediate rise in B.O.D., grease and settleable solids content of the sewage and to extend this effect of the additive through the use of smaller applications. A 6,000 ft. section of the sewer previously used was chosen. There were only five laterals between the sampling points and each of these laterals served only one or two blocks of homes. A series of upstream and downstream samples were taken to determine the normal variations (without the additive) in the sewage. The results showed no definite variation in B.O.D., grease content, or bacterial plate count; however, a slight decrease in the 1-hr. settleable solids was apparent at the downstream point. Applications were made at six different points, namely a 5-lb. application near the upper end of the sewer and 2-lb. applications in each of the five laterals. A total of 15 lb. of additive was used. Samples were taken every 2 hr. above and below the points of application, starting 12 hr. after application. The flow time between the two sampling points was about 1 hr. Two weeks later the applications were repeated and a second series of 2-hr. samples were taken, starting 36 hr. after application of the additive. The results of this test are given in Table III.

Chloroben

The second study was to compare chloroben with the biological additives using the same criteria. The tests using chloroben were made on the same section of sewer as the experiment using biological additives. Samples were taken above and below the point of application, at 7:00 AM each day for a period of one month.

Chloroben was applied at a varying

TABLE II.—Effect of Biological Additive at Downstream Sampling Point, Second Test

Date (1955)	B.O.D. (p.p.m.)	Grease (p.p.m.)	Settleable Solids (p.p.m.)	pH	Plate Count (bacteria per ml.)
June					
2	144	35	1,400	7.5	50,000
4	194	43	800	7.55	150,000
6	122	48	500	7.5	480,000
7	219	53	1,000	7.5	1,400,000
8	312	52	2,300	7.5	600,000
10	188	25	800	7.6	320,000
12	138	27	800	7.55	—
13	132	47	2,400	7.55	950,000
15	151	29	900	7.5	1,200,000
17	90	22	600	7.5	720,000
20	85	17	1,100	7.3	510,000
23	149	35	1,100	7.4	1,200,000
25	117	31	900	7.55	2,000,000
27	115	41	800	7.4	1,100,000
29	270	155	3,500	7.4	1,500,000
Normal Avg.	235	48	2,400	—	650,000

TABLE III.—Consistency of Immediate Effect of Biological Additive [1]

Date and Time (1955)	B.O.D. (p.p.m.)		Grease[2] (p.p.m.)		Settleable Solids[2] (p.p.m.)		pH		Plate Count (bacteria per ml.)	
	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream
July 6										
12:30 PM	390	390	227	112	6,000	7,000	7.3	7.15	170,000	2,100,000
2:30 PM	363	340					6.95	7.2	610,000	4,200,000
4:30 PM	332	347	98	112	9,000	10,000	7.1	7.1	690,000	1,200,000
6:30 PM	342	361					7.4	7.15	160,000	710,000
8:30 PM	275	332	98	120	6,000	10,000	7.05	7.1	640,000	700,000
10:30 PM	275	327					7.0	7.2	400,000	490,000
July 7										
12:30 AM	232	292	75	90	3,000	5,000	7.15	7.1	30,000	1,300,000
2:30 AM	253	267					7.35	7.25	30,000	240,000
4:30 AM	176	231	29	39	500	1,500	7.40	7.35	100,000	160,000
6:30 AM	194	194					7.45	7.45	10,000	250,000
8:30 AM	302	227	108	101	8,000	7,000	7.5	7.55	130,000	500,000
10:30 AM	488	308					7.35	7.3	200,000	120,000
12:30 PM	332	425	120	128	3,500	7,500	7.1	7.3	800,000	530,000
July 21										
12:30 PM	507	548	126	200	12,000	15,000	7.0	7.05	460,000	440,000
2:30 PM	422	420					6.8	7.05	70,000	600,000
4:30 PM	485	392	164	128	15,000	9,000	6.9	7.15	770,000	1,200,000
6:30 PM	317	328					7.0	7.1	—	—
8:30 PM	442	370	104	130	9,000	7,000	6.95	6.9	—	—
10:30 PM	390	310					6.8	7.0	—	—
July 22										
12:30 AM	335	375	77	89	6,000	4,000	7.2	7.1	—	—
2:30 AM	295	352					7.1	7.2	—	—
4:30 AM	272	275	33	43	1,000	1,200	7.35	7.3	—	—
6:30 AM	250	250					7.25	7.3	—	—
8:30 AM	422	340	116	82	5,200	3,500	7.5	7.6	—	—
10:30 AM	515	468					7.3	7.1	—	—
12:30 PM	420	495	113	150	5,000	8,500	7.05	7.15	—	—

[1] First samples collected 12 hr. after application of the additive.
[2] Four-hour composite samples.

rate to give a nearly constant concentration of the chemical in the sewage. The initial application was slightly less than 1 p.p.m. for one week; it was increased to 1.5 p.p.m. and then to 2 p.p.m.

Results and Conclusions

The tests showed that the addition of a biological additive had the immediate effect of increasing the values for grease content, settleable solids and bacteria plate count. A more stable pH resulted, with perhaps an increase in B.O.D. This immediate effect lasted only about 48 hr., after which the B.O.D. and settleable solids decreased to less than normal for about three weeks. The bacteria plate count also decreased, but averaged above normal. The pH was little affected.

The results herein indicate possible improvement but statistically the data do not provide a clear enough departure to enable the authors to draw definite conclusions without further study. Small dosage technique appears better, and environmental changes as indicated by B.O.D. and solids determination appear to be useful in dosage control. The results also indicate that the B.O.D. and settleable solids may be used to determine the end point of an application.

No noticeable change in the B.O.D., pH, or settleable solids was affected by

chloroben. A small decrease was noted in the bacterial count, but this could have been a result of the poorly controlled conditions. The field project was abandoned in favor of a laboratory project in which conditions could be better controlled.

Future Studies

At the present time, laboratory studies are underway on a small model section of sewer where performance can be observed to determine if slimes and grease can be removed by biological additives and chloroben, and suppressed by alkaline chlorination.

Once these studies are completed, 8 split, short sections of sewer will be studied. In addition to actual physical observation of the slime growths, and the alteration in environment as determined by the standard tests used in Oklahoma City studies, Redox potential readings are planned. Basically, the points of interest are:

1. The evaluation of the effectiveness of Redox measurements in determining the effects of the various odor control methods used.
2. The obtaining of more conclusive evidence that additives produce environmental changes in the flowing sewage.
3. The effect of increased dosages of biological additives on the cyclic sloughing of sewer slimes, from the standpoint of food supply.
4. The effect of hydraulic variables (flow depth, silt load, pipe material, etc.) on slime and odor development.
5. The effect of additives on slime matrix in the absence of a flowing sewage.

Acknowledgment

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ADMINISTRATIVE ENGINEERS

The national shortage of engineers is commonly attributed to the disinterest of high school students who shun the rigors of higher technical education. Now another cause for the shortage has been indicated at the other end of the ladder.

A recent survey by Carnegie Institute of Technology revealed that a majority of science and engineering alumni are functioning in the higher echelons of administration and management. Results of a questionnaire sent to 18,000 alumni revealed that only one-fourth (2,391) of those holding science or engineering degrees listed their occupation as engineer, the rest were in administration, related occupations or had left the field entirely.

Industrial Wastes

CYANIDE AND CHROMIUM RECOVERY FROM PLATING WASTES *

By Louis Weisberg and E. J. Quinlan

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This paper describes the treatment of electroplating wastes produced by Channel Master Corporation in Ellenville, New York. The most striking feature of this operation is the recovery of most of the so-called waste materials in useful form instead of destroying them by chemical treatment, as is the common practice.

Channel Master Corporation manufactures television antennas, some parts of which are made of steel. These parts are electroplated with zinc to protect them against rusting, and for additional protection the zinc-coated steel is given a dip in a solution which consists largely of chromic acid.

Sources of Wastes

There are three principal sources of waste in these operations, as follows:

1. Before the steel can be plated, it has to be cleaned until it is free from oil, grease, and oxide. This requires treatment with one or more strongly alkaline solutions to remove oil and grease, dipping in acid solutions to dissolve oxide and scale, and rinsing in running water between and after these various cleaning operations. Accordingly, these rinse waters contain some alkali and some acid. Eventually the cleaning and dipping solutions become fouled and have to be dumped. Since the acid and alkali tend to neutralize each other, these wastes are allowed to mix and are collected together.

2. The zinc plating solution contains cyanide as well as dissolved zinc and alkali. When the zinc-coated parts are rinsed after plating, as they must be, the rinse waters pick up zinc and cyanide, both of which are highly toxic. Therefore, these rinse waters are unsuitable for discharge into many streams unless they are sufficiently diluted or treated.

3. After the zinc-coated steel has gone through the chromic acid dip, it is rinsed again in running water. This rinse water contains enough chromic acid to render it objectionable. In addition, the chromic acid dip gradually dissolves enough zinc, iron, and trivalent chromium so that it has to be dumped either entirely or in part. Since this solution contains a much higher concentration of chromic acid than the rinse water, it constitutes the principal source of chromic acid pollution.

Each of the three classes of waste mentioned is kept apart with as little opportunity for mixing with the others as can be arranged. This is essential if anything useful is to be recovered.

The collecting system includes a number of sumps and holding tanks, as well as drainage ditches, situated so as to catch any accidental spillage or

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overflow of waste-bearing solutions or rinses.

Recovery of waste materials from the mixed acid and alkaline wastes is of questionable value. These mixed wastes are collected in one of two holding tanks, where they are finally neutralized by adding either acid or alkali, as necessary, so as to bring the mixture to a pH between 6.5 and 8.5. After the mixture has been neutralized, any precipitate that forms is allowed to settle. The clear, neutral effluent is run off to a nearby creek. The sludge is cleaned out at intervals and dumped. Each of the holding tanks referred to here holds 15,000 gal.; while one is being checked and discharged, the other is filling.

If traces of cyanide are found to be present, the mixed wastes are treated with hypochlorite in a tank provided for this purpose. No attempt is made to recover this cyanide because it is so dilute and usually there is so little of it that recovery would be uneconomical. The same holds true for chromic acid. If any is present, it is reduced to trivalent chromium by adding sodium bisulfite and sulfuric acid. The trivalent chromium is then precipitated by adding lime and settling as previously described.

The cyanide and chromic acid in the second and third types of waste previously mentioned are well worth recovering. Accordingly, a separate closed circuit has been set up for each of these waste discharges. Except for accidental contamination, which has proved negligible, there is no mixing of the cyanide and chromic acid wastes. Finally, there is no discharge of either cyanide or chromic acid anywhere outside the Channel Master plant. All but an insignificant portion of both these materials is recovered and used again.

Cyanide Recovery

The rinse water from the zinc plating operation contains substantially all the cyanide that ordinarily goes to waste. Recovery is effected by evaporating the rinse water until the concentration of cyanide in the evaporated solution is at least equal to that in the plating tank. This concentrate is pumped from the evaporator to a holding tank, from which it is eventually returned to the plating tank. Since the rinse water contains not only cyanide, but also zinc and other constituents of the plating solution, all in their proper proportions, evaporation recovers not only the cyanide but also the rest of the plating solution as well.

To keep evaporation costs from becoming excessive, it is necessary to avoid any more dilution than is absolutely necessary in rinsing the plated work. To produce a concentrated rinse and at the same time accomplish the most efficient washing possible, use is made of the countercurrent principle, as shown in Figure 1. A four-

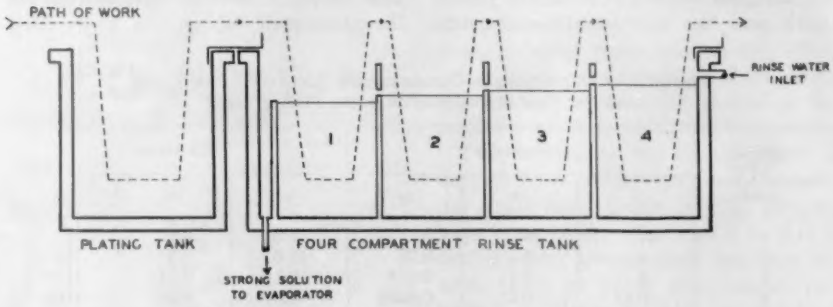

FIGURE 1.—Countercurrent recovery rinse system.

compartment tank is arranged so that the plated work is carried through the four compartments in succession while rinse water flows through in the opposite direction. The same wash water is thus used four times, in effect. Fresh water is brought in contact with work that has already been rinsed in the three preceding compartments; as the water moves through successive compartments, the concentration of cyanide which it carries increases. In the last compartment, the rinse water meets plated work coming directly from the plating tank and carrying undiluted plating solution. In this stage, therefore, the concentration of cyanide in the rinse water reaches its highest point—a point at which evaporation has been found to be economical.

The counterflow principle in rinsing is an essential feature in this method of recovering cyanide because it produces the highest attainable concentration of cyanide in the solution to be evaporated and at the same time reduces the concentration of cyanide on the work leaving the rinse system to the lowest point that can be attained with a given amount of wash water.

When a tank such as that shown in Figure 1 is operated at a steady rate for a period of time, a steady state is approached in which the composition in each compartment undergoes no further change. It is a simple matter to find what these compositions must be by setting up a material balance, providing the degree of mixing between the solution carried over on the plated work and the solution in each compartment is known or can be estimated. In the ideal case, which is called "good mixing," the composition of the solution carried out of each compartment will be the same as the composition left behind in that compartment.

For comparison, a similar calculation is shown in Table I for the case where the composition of the solution leaving each compartment is assumed to lie half-way between the composition in that compartment and the composition in the preceding compartment, or in the plating tank, as the case may be. This type of mixing, which is referred to as "half mixing," is fairly representative of rather poor mixing.

The governing factors, besides the degree of mixing, are the ratio between the volume, or weight, of rinse water and the volume, or weight, of water carried out of the plating solution on the plated work and the number of stages or compartments.

Table II shows the percentage recovery to be expected on the basis of calculations similar to those in Table I.

In practice the flow of water through the countercurrent rinse tank has been regulated so that it falls somewhere between 10 and 15 times the quantity of plating solution dragged out of the plating tank on the work per unit time. Since this is a small flow compared to what is commonly used in plating rinse tanks, it is important to provide a regulator sensitive enough to handle the small flow and to maintain an even flow independent of fluctuations in line pressure.

TABLE I.—Compositions in Countercurrent Recovery Rinse System (as Per Cent of Composition in the Plating Tank)

Compartment \ Water Feed Ratio	Good Mixing			Half Mixing		
	5	10	20	5	10	20
1	20	10	5	19.6	9.9	5
2	4	1	0.25	11.6	5.4	2.6
3	0.77	0.1	0.012	2.7	0.71	0.18
4	0.13	0.01	0.0006	1.0	0.26	0.06

TABLE II.—Percentage Recovery of Cyanide in Countercurrent Recovery Rinse

Compartment \ Water Feed Ratio	Good Mixing			Half Mixing		
	5	10	20	5	10	20
1	80	90	95	40	45	47
2	96	99	99.8	84	92	96
3	99.2	99.9	99.98	93	97	98.6
4	99.8	99.99	99.999	98	99.5	99.9

The flow in the Channel Master rinse tanks ranges from 0.5 to 1.5 g.p.m. That these flows are adequate may be seen from Table III, which shows some typical results obtained under actual operating conditions. The values given for the first two stages represent averages of 12 separate analyses made on 12 different days. The water feed ratio estimated from these averages, on the assumption of good mixing, is 13.7. No analyses were made on water from the third compartment. Therefore, the values given there are merely estimates based on the assumption that the mixing was good and the water feed ratio 13.7.

The cyanide concentration for the fourth stage is the highest found at any time in several determinations. It appears to be out of line with the other values, but this is readily understood in view of the fact that there is a slight entrainment of cyanide in the steam coming from the evaporator; this steam is condensed and the water thus obtained is recirculated through the rinse tank.

This test was made with parts that are comparatively easy to rinse and with good mixing in each compartment. Similar results probably hold good for all antenna parts with the exception of masts, which are made of tubing and which are plated in a horizontal position so drainage is not complete.

TABLE III.—Performance Test on Countercurrent Rinse Tank

Compartment	Cyanide Content, as HCN	
	(oz./gal.)	(p.p.m.)
1	0.286	2,145
2	0.021	157
3	0.0015*	11*
4	0.0007	5

* Estimate.

The overflow from the rinse tank goes to a holding tank and from there passes through a preheater into a double-effect evaporator. The reason for using a double-effect evaporator rather than a single-effect unit is to conserve steam, the cost of which is rather high at the Channel Master plant.

A double-effect evaporator consists essentially of two evaporators connected in series, but operating at different pressures and therefore at different temperatures. Steam produced at the higher temperature in one effect is used to evaporate more water in the effect operating at the lower temperature.

Specifically, in the present case steam at about 15 p.s.i. is supplied to the preheater and to the heating coils of the first effect. A vacuum of 18 in. of mercury is maintained in the first effect; so the boiling temperature there is approximately 180° F., and the steam or water vapor leaving this effect has a temperature not far from this; for example, it would probably be available at about 175° F.

The vacuum in the second effect is kept at 28 in. of mercury; so the boiling point there drops to 115° or perhaps even lower. The result is that a double-effect arrangement produces almost twice as much evaporation per pound of steam as can be obtained with just one effect. It is estimated

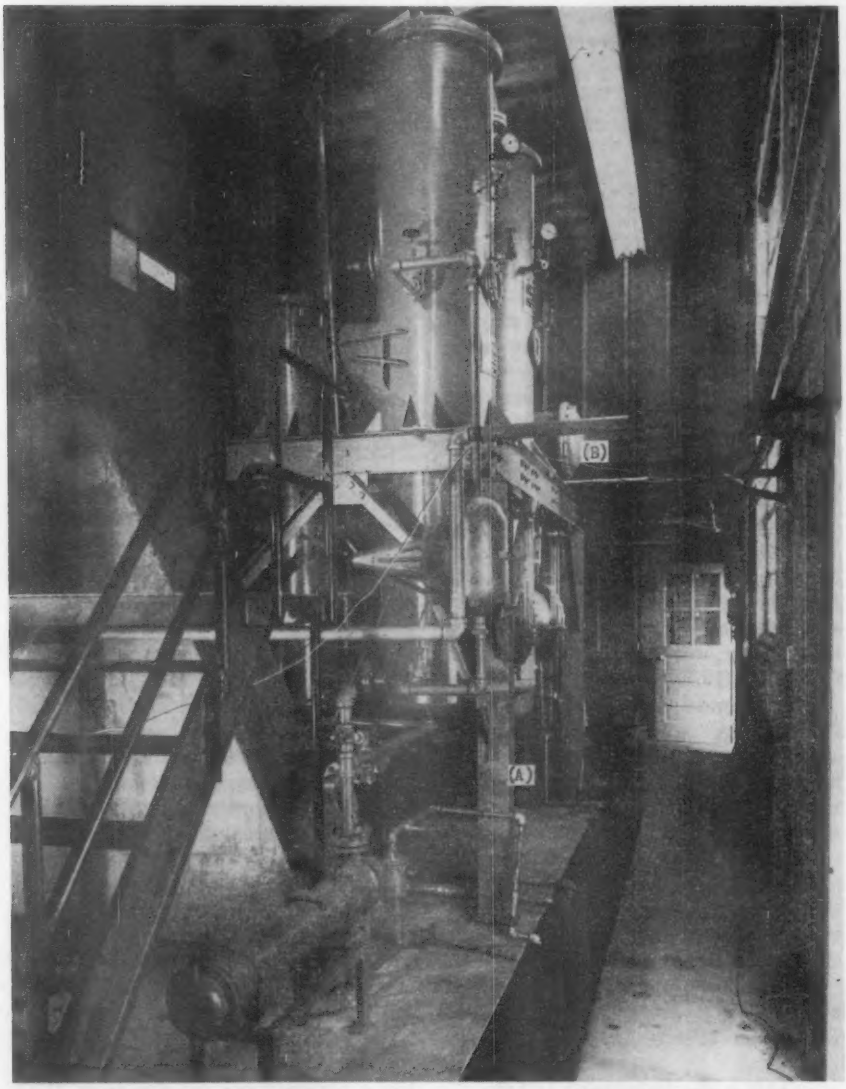

FIGURE 2.—Double-effect evaporator with vacuum pump (A) and horizontal vessel (B).

that when it is operating at capacity, the second effect will save enough steam to pay for itself, under the conditions prevailing, in about 18 months.

The steam input to the evaporator is regulated by a float-type control operating on the solution level in the holding tank previously mentioned. The solution level within the evaporator is also controlled automatically.

Figure 2 shows the evaporator, with the preheater in the foreground, followed by the first and second effects. A mechanical vacuum pump (A) in the background has now been replaced by a two-stage steam ejector. The

mechanical pump was used for a while because steam at 90 to 100 p.s.i., which is necessary to operate the ejector, was not available at that time.

The horizontal vessel (B) on top of the platform in the background is the main surface condenser. Underneath the condenser is the condensate receiver. The distilled water which collects in this receiver is pumped out automatically whenever it reaches a set level in the receiver. This water is used as rinse water in the countercurrent rinse tanks. Steam condensed in the preheater and in the coils of the first effect contains no entrained cyanide and can be returned to the boiler.

The distilled water recirculated through the rinse tanks contains small amounts of cyanide as a result of entrainment within the evaporator. To keep entrainment within bounds, each evaporator is provided with a mesh de-mister in the vapor head. Operating experience indicates that entrainment amounts to less than 5 p.p.m. Since this water is recirculated and none of it goes to waste, there is no danger of its causing pollution. True, this leaves a slight residue of cyanide on the plated work leaving the last compartment of the rinse tank, but this is oxidized and destroyed in the chromic acid dip that follows.

The concentrate produced in the second effect is brought up to approximately the same concentration as the solution in the zinc plating tanks. Since the liquor in the evaporator is under vacuum, the concentrate has to be pumped out at intervals. The pump then delivers it to a holding tank, from which it is distributed to the various plating tanks as make-up is required.

Occasionally this concentrate contains a small amount of chromate as a result of accidental contamination somewhere along the line. In this event, sodium hydrosulfite is added in the holding tank to reduce the chromate to trivalent chromium, which is harmless. It is the practice to treat the Channel Master zinc plating solutions with sodium sulfide at intervals to precipitate heavy metals and other impurities. This treatment seems to take care of all accumulated impurities arising from continued re-use of the same solution, and it has not been necessary to discard any plating solution or make use of any other purification procedure.

Some platers have expressed amazement at the fact that there has been no serious build-up of carbonate in the plating solution due to decomposition of cyanide during evaporation. This possibility was investigated in the laboratory and it was found that formation of carbonate does not take place when cyanide solutions are evaporated in vacuum. Apparently carbonate formation takes place in cyanide solutions at an appreciable rate only when they are exposed to carbon dioxide, as is the case when such solutions are heated in the presence of air.

Steam used in the evaporator for heating comes to about 70 lb., at 15 p.s.i., per pound of sodium cyanide recovered. In addition, the ejector requires another 40 lb. of steam at 90 to 100 p.s.i. per pound of sodium cyanide recovered. The condenser requires about 200 gal. of cooling water (at 60° F.) per pound of sodium cyanide. With steam at $1.00 per 1,000 lb. and cooling water at $0.07 per 1,000 gal., steam and water costs for evaporation add up to about $0.12 per pound of sodium cyanide, which is approximately the current price of this material. This is the main cost, since the evaporator requires less than one man-hour of direct labor per shift to operate it.

The Channel Master unit is recovering wastes from about 11,000 gal. of cyanide zinc plating solution. The maximum recovery with this unit is approximately 160 lb. of sodium cyanide per day. Of course, zinc and

other constituents of the plating solution are recovered at the same time.

The usual method of handling cyanide wastes is to destroy the cyanide by oxidizing it with chlorine and sodium hydroxide. The cost of chemicals, if this method were used at Ellenville, would be at least $0.60 per pound of sodium cyanide, to which must be added the cost of replacing the cyanide, zinc, and other materials which are completely lost by this method. This saving amounts to more than $100 a day for Channel Master Corporation.

Chromate Recovery

It has already been mentioned that chromic acid wastes occur in Channel Master's operations in two ways: (a) as the concentrated chromic acid dip solution is used, it becomes contaminated with zinc, trivalent chromium, and iron, its effectiveness is diminished and it must be discarded, in whole or in part; and (b) as rinse water from this dipping operation.

If the concentration of chromic acid in the rinse water becomes too high, the result is unsatisfactory. It is necessary here to use a large volume of rinse water (countercurrent rinsing is out of the question). At best, recovery of such dilute chromic acid is a break-even proposition, but it is nevertheless the least expensive way to deal with a potentially serious pollution problem. On the other hand, recovery of the more concentrated chromic acid from used dip solutions yields substantial savings.

Recovery of chromic acid in both instances is based on ion exchange. The basic idea of using ion exchange to clean up and recover chromic acid is not new (1); it has been used in connection with aluminum anodizing solutions, with chromium plating solutions, and with copper stripping solutions. However, the use of ion exchange in connection with chromic acid solutions for brightening zinc coatings on steel is new, so far as is known, and involves complications not encountered in earlier applications.

Chromic acid in solution is present principally in the form of positively charged hydrogen ions and negatively charged chromate ions. Any dissolved zinc, iron, or trivalent chromium will be present as positively charged ions. Accordingly, a used chromic acid dip contains negatively charged chromate ions together with positively charged zinc, trivalent chromium, and iron ions. Ion exchange makes it possible to remove these metal ions from the solution and replace them with an electrically equivalent quantity of hydrogen ions.

The resulting solution contains only positively charged hydrogen ions and negatively charged chromate ions—in short, the solution now contains substantially pure chromic acid. In practice, the exchange is seldom that complete; but it is entirely practicable to keep impurities at such a low level that they do not interfere with effective working of the dip solution.

Ion exchange is carried out in columns such as those shown in Figure 3. Each column is filled with a bed of synthetic ion exchange resin, an insoluble granular solid which, depending on its make-up, has the property of splitting off either positive or negative ions and giving these up to the solution with which it is in contact and taking up in exchange from the solution an electrically equivalent quantity of ions bearing the same charge. There are two main types of ion exchange resin: one type is used to exchange positively charged ions, the other to exchange negatively charged ions (2).

The direction in which the exchange takes place depends on the relative concentrations of the ions involved in the solution that is in contact with the resin. Accordingly, after the cation exchange resin becomes loaded with zinc, iron, and trivalent chromium, it

can be regenerated by treating it with a solution containing a high concentration of hydrogens ions; for example, a 10 per cent solution of sulfuric acid.

Regeneration is important because the resin is too expensive to be used once and then thrown away. The useful life of the resin should be measured in hundreds of cycles, providing it is not abused. When the cation resin is treated with 10 per cent sulfuric acid, zinc, iron and trivalent chromium go into solution. An equivalent quantity of hydrogen ions enter the resin bed, producing once more a cation exchange resin in the hydrogen form, ready to be used again after it has been washed with water to remove the last of the regenerant solution.

The regenerant solution, together

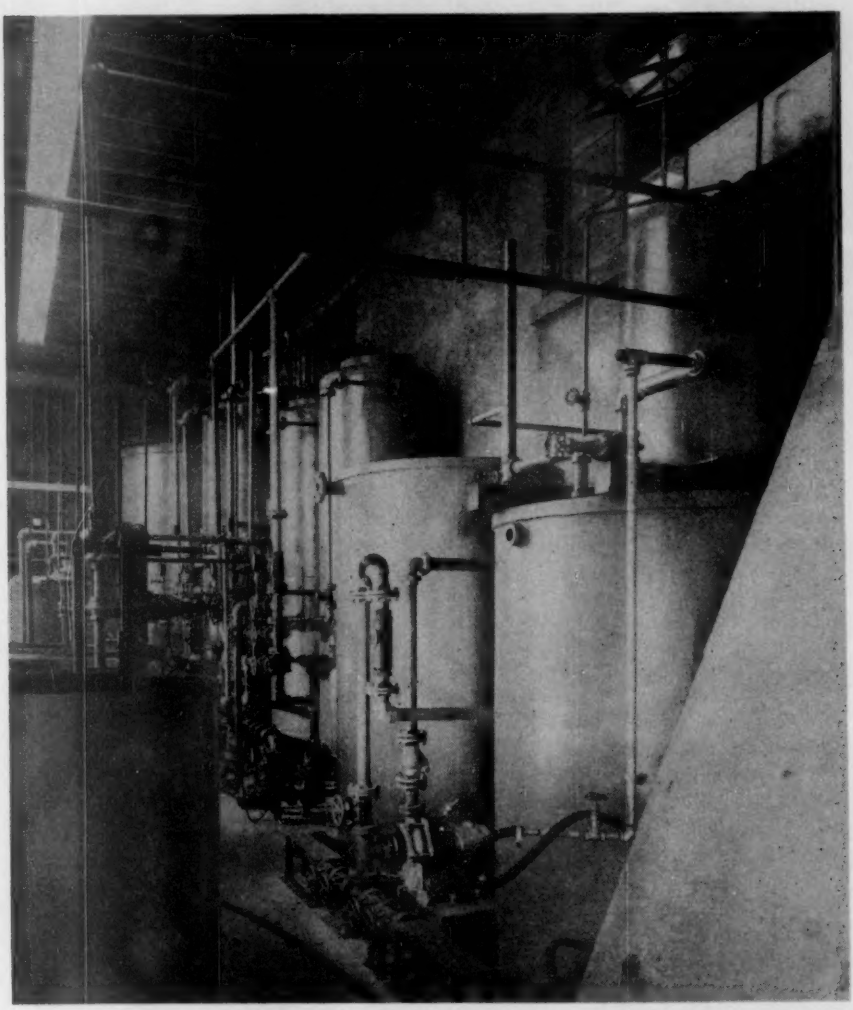

FIGURE 3.—Ion exchangers and auxiliary equipment for chromate, zinc and iron recovery.

with these washings from the cation exchanger, contains substantially all the zinc, iron, and trivalent chromium taken up by the chromic acid dip along with some excess sulfuric acid. To dispose of this solution, it is treated with lime to neutralize the acid and precipitate a sludge consisting of calcium sulfate and oxides, or hydroxides, of zinc, iron, and trivalent chromium. After the sludge has settled, the clear neutral effluent is run off to waste. The sludge is dumped.

It is noteworthy that this effluent and sludge produced in regenerating the cation exchange resin constitute the only waste products that have to be disposed of outside the Channel Master plant from the entire chromate recovery process.

The cation exchanger has to be washed with water after the chromic acid has passed through it and again after the regenerating solution has passed through. This, of course, produces some dilution. In general, it is difficult to recover chromic acid at a concentration much above 100 g. per liter. Since the Channel Master dip solution uses a higher concentration of chromic acid, some water has to be evaporated. For the time being, the evaporation is being carried out in an open stainless steel (type 316) tank fitted with a stainless steel coil. Some corrosion has been observed, but it has not proved serious.

A solu-bridge, which follows changes in electrical resistance, is used to control the water valves, thus keeping dilution to a minimum.

The chromic acid dip solution is passed through the cation exchanger at regular intervals so as to keep the zinc coating coming out bright and with satisfactory corrosion resistance. Ion exchange not only saves a substantial amount of chromic acid, but also helps to maintain a higher standard of quality with respect to the appearance and corrosion resistance of the coating than was attained before.

A complicating factor may be noted in passing but need not be discussed at length because it has little effect on the waste treatment process. This complication arises from the fact that the chromic acid dip solution contains several other acids in addition to chromic acid. Although these other acids are present in relatively small amounts and although they too are present in solution as negatively charged ions, some of these ions combine with trivalent chromium ions to form postively charged complex ions which may be removed from the solution through the action of the cation exchange resin. This effect has to be taken into account and so it became necessary to develop methods for analyzing these rather complex mixtures so as to maintain and replenish the dip solution properly.

Recovery of chromic acid from the rinse water is carried out in quite a different manner from that previously described. The chromic acid concentration in the rinse water is much less than in the dip solution. In fact, it is purposely kept low so as to obtain maximum brightness and corrosion resistance. Essentially the rinse water contains positively charged hydrogen ions and negatively charged chromate ions. The chromate ions are removed from the water by passing it through an anion exchange resin. The anion exchange resin gives up hydroxyl ions to the water in exchange for the chromate ions.

Now the anion exchange resin is regenerated by treating it with a 10 per cent solution of sodium hydroxide. The previous action is reversed; the resin now gives up chromate ions to the regenerating solution and takes up hydroxyl ions in their place. The resulting solution—nominally a mixture of sodium chromate and some excess sodium hydroxide—contains positively charged sodium ions, together with negatively charged chromate and hydroxyl ions. This solution is now

passed through a cation exchange resin, which takes out the sodium ions and replaces them with hydrogen ions. The only ions left are, therefore, hydrogen, chromate and hydroxyl. Excess hydrogen ions unite with the hydroxyl ions to form water, leaving a solution of substantially pure chromic acid in water. In this process, the chromic acid solution produced at the end is much more concentrated than the rinse water, but it is still not concentrated enough to be used in replenishing Channel Master's chromic acid solutions. Evaporation of some water is required, therefore, before this recovered chromic acid can be used.

Both the yield and the concentration of the chromic acid recovered can be increased by using a split regeneration technic, such as has been described by Keating, Dvorin and Calise (3). They split the sodium hydroxide solution used to regenerate the anion exchange resin into three parts and use in countercurrent fashion. They also divide the sulfuric acid used to regenerate the cation exchange resin into two portions, which again are used in accordance with the countercurrent principle. This procedure results in an increased recovery of chromic acid, an increased concentration of the recovered acid, and an appreciable saving in the cost of chemicals used for regenerating the ion exchange resins.

The cation exchange resin comes in contact with a solution containing 150 g. of chromic acid per liter, whereas the anion exchange resin is too sensitive to tolerate concentrations above 1,000 p.p.m. In addition, the anion exchange resin costs about three times as much as the cation resin.

It may be of interest to come back briefly to what is done with the rinse water after it passes through the anion exchanger and gives up its chromic acid. This water is too good to throw away. By passing it through a cation exchanger it is stripped of any positive ions that may be present. This kind of water, which has been stripped of both positive and negative ions, is spoken of as demineralized water. Its purity is equal to, or better than, distilled water. It is recirculated and used again as rinse water. The use of demineralized water for rinsing after the chromic acid dip is believed to be responsible, in part at least, for the improved quality of the work since the ion exchange process was put in operation.

Although the array of valves in Figure 3 looks formidable, the operation of the ion exchange unit is really fairly simple. A few steps have been set up for automatic control, but for the most part operation is manual. Full automatic control would add substantially to the cost, especially in the case of a small unit, such as this one is.

Costs of chromic acid recovery have been discussed in detail by Bueltman (4), although he does not include the cost of concentrating the acid by evaporation, as is done at Channel Master Corporation. As has already been mentioned, the cost of recovering chromic acid from the rinse water is barely self-supporting, but purifying and recovering chromic acid from dip solutions produces a handsome return. Channel Master Corporation operates about 700 gal. of these dips. The monthly saving from chromic acid recovery is now running over $3,000. This is without taking account of a considerable improvement in the quality of the work that is being turned out now as compared to the quality produced before the ion exchange process was placed in operation.

The area required for the cyanide and chromic acid recovery equipment is 1,040 sq. ft., comprising a space 80 ft. long, 13 ft. wide, and a ceiling height of 20 ft. The cost of the entire installation, including all parts of the waste handling system required to classify and segregate the three different types of waste, comes to a total of approximately $100,000.

In view of the substantial savings achieved, the return on the investment would appear to be satisfactory. No cyanide or chromic acid is being discharged to waste and all applicable regulations in regard to pollution are being met.

Acknowledgments

The authors are indebted to Harry Greenberg, Chief Electrical Engineer, and Harold Harris, Vice-President for Sales and Engineering, Channel Master Corporation, for advice and support in carrying this project through to a successful conclusion.

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APPLICATIONS FOR SANITARY ENGINEERING CERTIFICATION NOW AVAILABLE

The American Sanitary Engineering Intersociety Board, Inc. is now receiving applications from registered sanitary engineers who are interested in being certified by the Board. Those certified will be carried on a roster to be known as the American Academy of Sanitary Engineering.

Certification by the Board is patterned after the specialty boards of the American Medical Society. Each applicant must meet three basic requirements:

1. Be currently registered as a professional engineer in one of the states of the United States.
2. Be a graduate of an accredited college of engineering or have proved experience and practice.
3. Be engaged in some aspect of sanitary engineering with at least eight years satisfactory experience.

The examination will consist of two parts —written and oral. The written examination will be of the multiple choice type. A special committee is working on this task and it is planned to give the first examination early in 1957. Each candidate will also stand an oral examination before a board composed of diplomates of the Academy of Sanitary Engineering. It is anticipated that two general examinations will be held each year. An application fee of $10.00 must accompany each application. The examination fee is $25.00, whether or not the examination is waived.

First engineers to be certified by the Board will be those who have 15 years of satisfactory experience. This "founder" group will be certified without examination provided application is received prior to July 1, 1957.

Certification of the first group of sanitary engineers will culminate the efforts of various individuals interested in the professional recognition and advancement of sanitary engineers. Initial efforts were started almost five years ago. The careful planning that has gone into the organization of the American Sanitary Engineering Intersociety Board should make membership in it a most respected honor in the professional engineering field. Organizers of the Board include the American Society of Engineering Education, American Society of Civil Engineers, American Public Health Association, American Water Works Association and the Federation of Sewage and Industrial Wastes Associations. The Federation representatives for this activity are Ray Lawrence, Dwight Metzler and R. S. Rankin.

Copies of the Certificate of Incorporation and Bylaws, and application forms, may be obtained from Francis B. Elder, Secretary, American Sanitary Engineering Intersociety Board, Inc., 33 West 39th Street, New York 18, N. Y.

TRICKLING FILTER TREATMENT OF WASTES AT TWO MILK PROCESSING PLANTS *

By S. I. Zack

Chief, Sanitary Division, Gannett Fleming Corddry & Carpenter, Inc., Harrisburg, Pa.

In general, milk wastes are subject to treatment by the same biological processes applicable to sewage. However, seasonal milk loads, variation in rates of milk wastes discharged over a 24-hr. period, processing operations, concentration of dissolved organic matter in solution, low organic matter content in suspension, and other factors and characteristics, present problems which can be met only by an individually tailored design for each installation, whether milk wastes are treated separately or in combination with municipal sewage.

The author had the opportunity to design two milk waste plants which have been placed in operation recently, one for the Borden Company at Arcade, N. Y., and one for Abbotts Dairies, Inc., at Belleville, Pa. Although this presentation is intended primarily to cover the Arcade plant, design features of the Belleville plant have been included as a matter of added interest and for a comparison of individual features.

Plant Location and Operations

The Manufacturing Products Division of The Borden Company is situated in Arcade, N. Y. (pop. 1,821 by the 1950 Census), on the northern bank of Cattaraugus Creek approximately 10 miles from the headwaters. Powdered milk known as "Starlac" is produced from skim and condensed skim milk at this plant.

Whole milk is brought to the plant in cans and in tank trucks; skim milk and condensed skim milk are also brought to this plant in tank trucks. Cream is separated and made into butter.

A fairly uniform manufacturing schedule without the usual seasonal fluctuations is maintained. Normally about 120 persons are employed during a 24-hr. day, 7 days per week.

Water of potable quality, required for washing tanks, cans, and for sanitary purposes, is purchased from the Village of Arcade. Water for cooling purposes is pumped from Cattaraugus Creek.

In the past a part of the wastes was discharged to the village sewage treatment plant and part to the creek.

Source of Milk Wastes

Milk wastes discharged to the village sewers originated from the process involving the receiving of whole milk, weighing, can washing, cream separation, skim milk preparation, pasteurization, and butter making from separated cream. Wastes discharged to Cattaraugus Creek originated from processes in manufacturing powdered milk, such as superheating, evaporating, drying, sifting, packing, etc. Most of the sanitary sewage has been discharged to the village sewers, with only a small amount going to the creek.

Village Sewage Treatment Plant

The village sewage treatment plant includes a bar screen, Parshall flume,

* Presented at 1956 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 18–20, 1956.

Imhoff tank, standard rock filter and dosing tanks, final settling tank of limited capacity, glass covered sludge drying beds, and chlorinating facilities. This plant was designed for a population of 2,500 persons and an average flow of 250,000 g.p.d. Part of the construction funds were supplied by the Works Progress Administration.

Even with flows averaging only about 200,000 g.p.d., which included only 16,000 gal. of milk wastes, pooling difficulties were encountered on the standard rock filter and the state health authorities did not consider the effluent to be acceptable. At the same time, Borden was being asked by the Health Department to take the milk waste pollution out of Cattaraugus Creek. Because of the condition of the filter and effluent at the village plant, Borden was not permitted to discharge additional milk wastes to that plant and was being asked to take the milk wastes out of the village sewers.

The village and state officials, however, approved the installation of a temporary pump by Borden to recirculate filtered effluent in an endeavor to produce an acceptable effluent, and directives relating to disposal of milk wastes were held in abeyance pending the completion of an engineering investigation to determine the improvements needed at the village plant for handling all of the milk wastes.

Existing pooling of the filter was eliminated by recirculation supplemented by backflooding and heavy chlorination, resulting in an effluent improved to the extent that it was considered to be acceptable for the milk wastes and sewage being handled.

It was determined that the improvements and additions necessary for handling all of the Borden milk wastes could be made under a step program of about five years, at a total cost of about $100,000. Borden was agreeable to providing the funds for the improvements, and in addition to paying a substantial rental as its full proportionate share of the expense of operation and maintenance. It was found that the Village Board of Trustees could not legally bind itself to a long-term contract necessary for protection of the Borden Company. It therefore became necessary for the Borden Company to design and build its own waste treatment plant. Pending completion of this plant an agreement was made for handling the wastes then being discharged to the village plant.

Volumes and Pollution Loads

The Borden wastes were gaged and sampled on May 4, 5, and August 13 and 14, 1951. Total volumes of wastes and pollution loads found during both of these investigations are shown in Table I. Variations in waste flow rates during the May investigation are shown in Figure 1.

The volume of so-called polluted wastes found by these investigations varied from 47,000 to 183,000 g.p.d.,

TABLE I.—Waste Volumes and Pollution Loads, Borden Food Products Co., Arcade, N. Y.

Date (1951)	Milk Receipts (lb.)	Volume (g.p.d.)				B.O.D. (lb./day)			
		Polluted		Non-Polluted		Polluted		Non-Polluted	
		Total	Per 1,000 Lb. Milk	Total	Per 1,000 Lb. Milk	Total	Per 1,000 Lb. Milk	Total	Per 1,000 Lb. Milk
May 4	450,000	56,000	125	575,000	1,270	383	0.85	33	0.073
May 5	456,000	47,000	103	570,000	1,250	334	0.73	27	0.059
Aug. 13	479,000	172,000	360	1,016,000	2,120	494	1.03	93	0.19
Aug. 14	424,000	183,000	430	946,000	2,240	333	0.79	686[1]	1.62

[1] Due to numerous pan boil-overs.

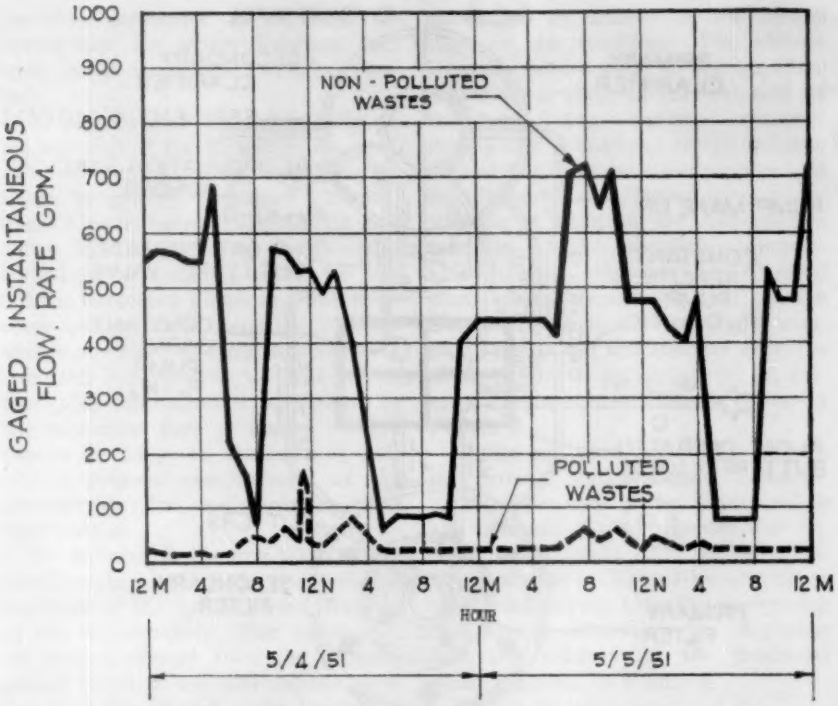

FIGURE 1.—Variations in waste flow rates, Borden Food Products Co., Arcade, N. Y.

or from 103 to 430 gal. of waste per 1,000 lb. of milk received. Pollution loads of the polluted wastes varied from 333 to 494 lb. of B.O.D. per day, equivalent to from 0.73 to 1.03 lb. of B.O.D. per 1,000 lb. of milk received. So-called non-polluted volumes consisting of spent cooling water from evaporators and refrigeration water ranged from 570,000 to 1,016,000 g.p.d., equivalent to from 1,260 to 2,240 gal. per 1,000 lb. of milk received.

During May, with more or less limited use of evaporator equipment, pollution loads of the spent cooling and refrigeration water ranged from 27 to 33 lb. of B.O.D. per day, or 0.059 to 0.073 lb. of B.O.D. per 1,000 lb. of milk received. With heavy use of the evaporation equipment in August, the B.O.D. content of these wastes ranged from 93 to 686 lb. per day, or from 0.19 to 1.62 lb. of B.O.D. per 1,000 lb. of milk received.

The high pollution loads found in August were due to excessive entrainment loss and numerous boil-overs of evaporation equipment. By installation of liquid level controls, alarms, careful operation, etc., the B.O.D. content of the spent cooling waters can normally be held to limits as found during the May investigation. These values are of a magnitude equal to those found in the effluent from the most efficient high-degree waste treatment plant. Consequently, as a matter of economy control of losses in spent cooling water is advocated, rather than treatment.

Treatment Plant Selection

Before the type of waste treatment plant was adopted for design and con-

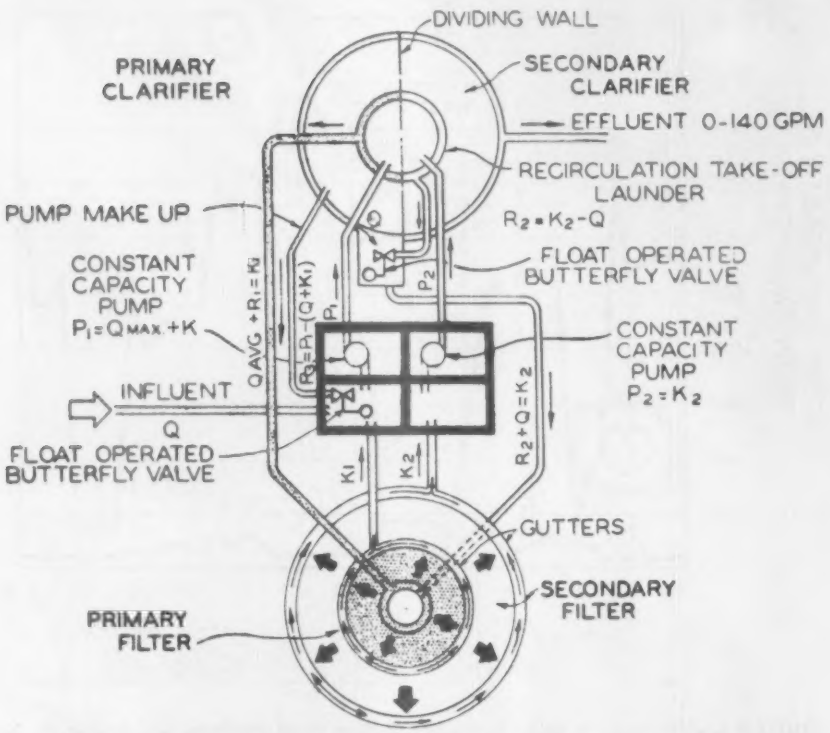

FIGURE 2.—Flow sheet for milk waste plant using duo-clarifier and duo-filter units, Arcade plant.

struction, consideration was given to one or more of the processes in the stage of development. These included such processes as long-period aeration, (40 hr. more or less) to obtain a treated effluent and to oxidize or burn up most of the sludge with discharge of such residual sludge to the stream with the effluent; and fill and draw, as well as continuous-flow, conventional activated sludge treatment. Estimates indicated that for the volume and strength of wastes involved these plants would be more costly both to construct and to operate than a high-rate recirculating trickling filter plant. Furthermore, the high-rate filter plant was considered to be less sensitive to changes in waste characteristics and subject to more positive control to give consistent results. The area available was not suitable for the construction of a standard trickling filter plant and a high-rate recirculating plant was adopted.

The plant selected was of the complete treatment type providing primary and secondary sedimentation, parallel double-stage high-rate rock filtration, separate sludge digestion, and facilities for drying of digested sludge solids. The principal units of the plant comprised a control building housing primary and secondary recirculation pumps, chlorination facilities, a so-called duo-clarifier * providing both primary and secondary sedimentation in one circular unit, a duo-filter * and distributor mechanism providing two stages of rock filtration in

* Equipment of the type marketed by the Dorr-Oliver Co.

one filter structure, an enclosed unheated tank for sludge digestion, and open earth embanked sand drying beds.

All milk wastes flow by gravity to the wet well of the first-stage constant capacity pumps. This well also receives by gravity first-stage filter effluent plus first-stage recirculation and a flow from the primary clarifier controlled by a butterfly valve for hydraulic balancing purposes. The first-stage pumps have capacity for the maximum flow of milk wastes or a balanced combination of milk waste flow plus recirculation equivalent to the maximum flow of wastes. These pumps discharge to the influent well of the primary compartment of the duo-clarifier for sedimentation and clarification.

The influent to the first stage of the duo-filter is taken off the recirculation launders of the primary compartment of the duo-clarifier. That portion of the settled effluent from the primary compartment of the duo-clarifier flowing over the effluent weirs located at the periphery of the tank is combined with recirculation from the secondary compartment of the duo-clarifier controlled by a butterfly valve, and jointly discharged by gravity to the second stage of the duo-filter. The effluent from the second stage of the duo-filter drains by gravity to the wet well of the second-stage constant capacity pumps and is pumped to the influent well of the secondary compartment of the duo-clarifier. Second-stage recirculation is taken off the recirculation launders of the secondary compartment of the duo-clarifier. Treated plant effluent constitutes that portion discharged from the secondary compartment of the duo-clarifier over the effluent weirs at its periphery. A diagram of the flow scheme is shown in Figure 2.

Sludge and scum removed from both the primary and secondary compartments of the duo-clarifier is pumped to an unheated sludge digester for decomposition and stabilization. Digested sludge is drained by gravity to open sand drying beds for dewatering and ultimate disposal as fill. A piping and flow diagram of the treatment plant is shown in Figure 3.

Design of Treatment Plant

The daily milk receipts each month range from a maximum of 160 per cent to a minimum of 60 per cent of the

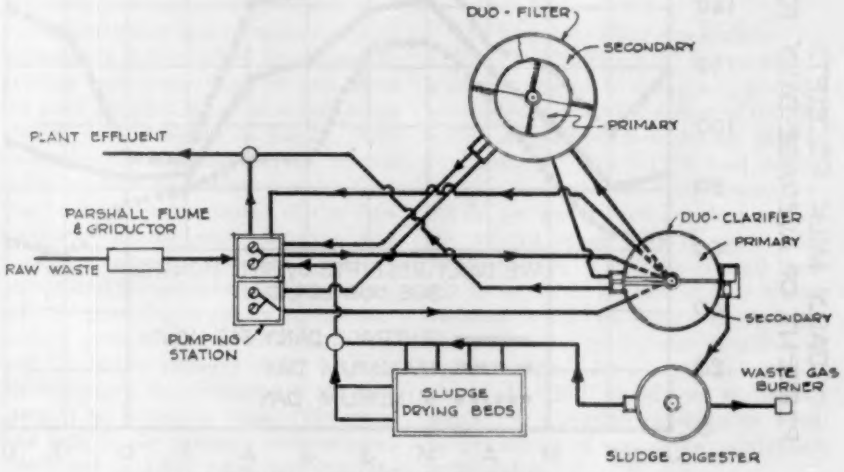

FIGURE 3.—Piping and flow diagram, Arcade plant.

daily average for the year. The ratios of average, maximum, and minimum milk receipts for each month as the ratio for the average daily for the year are shown in Figure 4.

To take care of reasonable growth and maximum variations, the plant design was based on milk receipts amounting to a maximum of 600,000 lb. per day; milk wastes amounting to an average of 175,000 g.p.d. and a maximum of 525,000 g.p.d.; and a milk waste pollution load amounting to 500 lb. of B.O.D. per day, calculated to result in a B.O.D. concentration of 340 p.p.m. and a population equivalent of 3,000. The design also provided for a suspended solids load of 250 lb. per day, calculated to be 170 p.p.m., and a population equivalent of 1,250 on the basis of 0.2 lb. suspended solids per capita per day. The milk waste volume and pollution load design basis are given in Table II.

TABLE II.—Design Basis—Flows and Pollution Loads of Two Milk Waste Treatment Plants

Item	Borden[1]	Abbotts[2]
Waste flow (g.p.d.):		
Average	175,000	30,000
Maximum	525,000	200,000
Minimum	0	0
B.O.D.:		
Pounds per day	500	325
P.p.m.	340	1,300
Pop. equiv., at 0.167 lb.	3,000	1,950
Suspended solids:		
Pounds per day	250	160
P.p.m.	170	640
Pop. equiv., at 0.20 lb.	1,250	800
Employees[3]	150	50
Milk receipts (lb./day)[3]	600,000	150,000

[1] Arcade, N. Y.
[2] Belleville, Pa.
[3] Maximum during flush season.

The basis of design of the pumping station and of the principal units of the treatment plant are given in Table III.

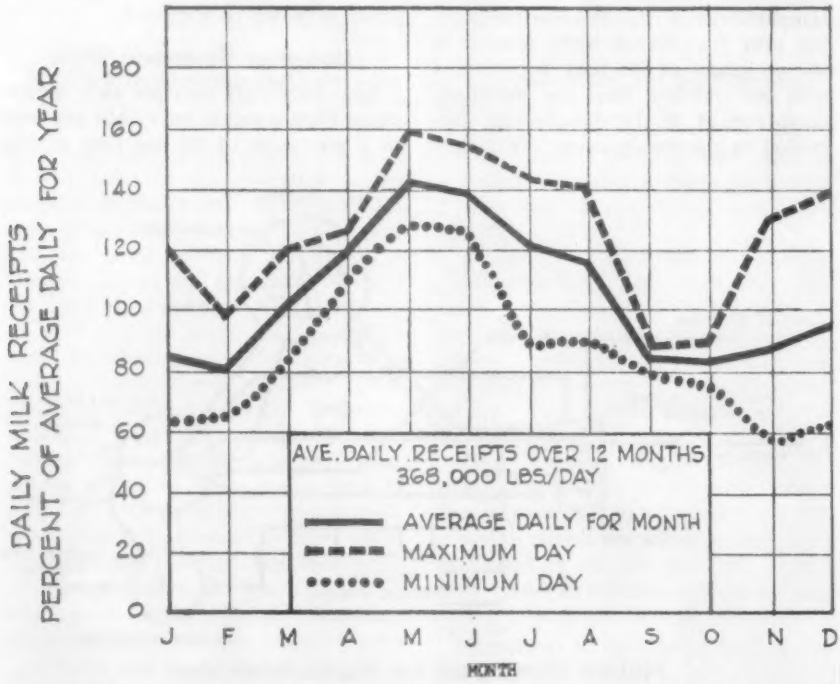

FIGURE 4.—Seasonal trends in milk receipts, Arcade plant, Borden Food Products Co.

TABLE III.—Design Basis, Milk Waste Treatment Plant Units

Unit	Item	Borden[1]	Abbotts[2]
Pumping station:			
Primary pumps	Flow (m.g.d.)	0.875	0.36
Secondary pumps	Flow (m.g.d.)	0.520	0.22
Duo-clarifier:			
Primary compt.	Flow (m.g.d.)	0.875	0.36
	Detention (hr.)	0.85	1.0
	Overflow (g.p.d./sq. ft.)	1,800	1,600
Secondary compt.	Flow (m.g.d.)	0.520	0.22
	Detention (hr.)	1.40	1.5
	Overflow (g.p.d./sq. ft.)	1,080	980
Over-all	Diameter (ft.)	34	24
	Sidewater depth (ft.)	8.5	8.25
Duo-filter:			
Primary	Flow (m.g.d.)	0.35	0.16
	B.O.D.[3] (lb./cu. yd./day)	3.80	2.42
	Hydr. load (m.g.a.d.)	21.6	10.7
Secondary	Flow (m.g.d.)	0.52	0.22
	B.O.D.[3] (lb./cu. yd./day)	0.77	0.61
	Hydr. load (m.g.a.d.)	25.7	30.0
Over-all	B.O.D.[3] (lb./cu. yd./day)	2.13	1.8
	Diameter (ft.)	43.6	35.0
	Rock depth (ft.)	4.0	6.0
Digester (unheated)	Susp. solids pop. equiv.	1,250	800
	Dig. capacity (cu. ft./cap.)	4.0	3.1
	Diameter (ft.)	25	15
	Sidewater depth (ft.)	10	14
Sand drying beds (open)	Pop. equivalent	600	400
	Drying area (sq. ft./cap.)	1.0	1.0
	Length (ft.)	40	24
	Width (ft.)	15.25	16.6

[1] Arcade, N. Y.
[2] Belleville, Pa.
[3] In terms of raw waste only.

The first-stage pumps were designed to handle a flow equal to five times the average milk waste flow, or 1.65 times the peak design flow. The second-stage pumps were designed to handle three times the average flow and an amount equal to the maximum sewage flow. The primary compartment of the duo-clarifier was designed for the full pumping capacity of the primary pumps and the secondary compartment for the pumping capacity of the secondary pumps, thus providing about 0.85 hr. in the primary and 1.4 hr. in the secondary compartment of the duo-clarifier as detention time. The overflow rate in the primary compartment was based on 1,800 g.p.d. and the rate in the secondary compartment on 1,080 g.p.d. per square foot.

The first-stage filter was designed for a flow of 350,000 g.p.d., amounting to a dosing rate of 21.6 m.g.a.d., and the second-stage filter for a flow of 525,000 g.p.d., amounting to a dosing rate of 25.7 m.g.a.d. The B.O.D. load on the first stage of the duo-filter amounts to 3.8 lb. per cubic yard per day, and on the second stage 0.77 lb. per cubic yard per day. Thus, the over-all loading in terms of B.O.D. in raw wastes amounts to 2.13 lb. per cubic yard per day. The sludge digester is unheated and is designed for a population equivalent of 1,250 based on suspended solids. A digestion capacity of 4 cu. ft. per capita of population equivalent is provided.

Although there is likely to be some solids produced from precipitation and

coalescence of solids in colloidal condition, it is believed that the digestion capacity provided is adequate. Since milk solids are primarily of digestible composition, drying bed capacity is provided for a population of 600 at 1 sq. ft. per capita of population equivalent. Very limited information is available from which to design digesters and drying beds; therefore, by necessity most digestion tanks and drying beds for milk wastes probably are larger than they need to be. Some reports have indicated that milk waste solids can be digested completely without residual sludge. However, because of the critical location of the treatment plant site it was considered essential to provide some drying beds in case it was necessary to remove sludge from the digester. The digester was equipped with the usual safety devices normally used in connection with the collection of sludge gas, and also with a waste gas burner for burning gas produced. Estimates indicated that sufficient gas would not be produced to make utilization feasible or practical.

Sanitary Sewage

Although it was originally planned to separate the sanitary sewage and continue to discharge it to the village sewage treatment plant, such separation was found to be difficult and costly, and it was decided to discharge the sanitary sewage from about 150 employees to the milk waste treatment plant. To make this practical and feasible a comminutor and bypass screen are being purchased.

Initial Operation

The Borden milk waste treatment plant was placed in operation during October 1955. No particularly difficult operating problems have been encountered. When operation of the digester was started it was seeded with sludge from the village sewage treatment plant and the pH of the sludge immediately changed from the acid to the alkaline side necessary for proper digestion. Build-up of biologic action in the trickling filter was rather slow because of the cold weather. As a result it was not possible to determine what efficiency was being obtained as a result of the treatment.

There is an indication that some short-circuiting exists from the primary compartment of the clarifier to the secondary compartment. As a result some milky appearance still exists in the effluent from the secondary filter. Some of this milkiness is expected to disappear when biologic activity optimum for purification of organic matter is attained. However, it is obvious that some physical changes in baffling and in recirculation will be necessary to eliminate completely the milkiness in the secondary effluent.

Abbotts Dairies Waste Treatment Plant

As a result of studies at the milk processing plant of Abbotts Dairies, Inc., at Belleville, Pa., a plant similar to the Borden plant was built.

The milk operations at Belleville consist of whole milk receiving, cooling, canning, pasteurizing, separating; whole and skim milk condensing; condensed skim milk drying; and the processing of butter, cream cheese, and ice cream mix. About 40 to 50 persons are employed in the summer months and the plant operates from 18 to 24 hr. per day. Approximately 30 persons are employed during the winter months when operation is from 12 to 18 hr. per day. Milk receipts vary from about 90,000 lb. per day in winter to 140,000 lb. per day in summer. The operations from which waste waters are discharged are as follows:

1. Washing and cleaning cans, floors, milk drain piping, and processing equipment.
2. Cooling, evaporation, drying, and refrigeration.
3. Sanitary facilities.

TABLE IV.—Waste Volumes and Pollution Loads, Abbotts Dairies, Belleville, Pa.

Date (1952)	Milk Receipts	Volume (g.p.d.)				B.O.D. (lb./day)			
		Polluted		Non-Polluted		Polluted		Non-Polluted	
		Total	Per 1,000 Lb. Milk	Total	Per 1,000 Lb. Milk	Total	Per 1,000 Lb. Milk	Total	Per 1,000 Lb. Milk
May 27*	150,000	27,000	180	384,000	2,560	365	2.43*	26	0.17
May 28*	150,000	27,000	180	342,000	2,280	350	2.33*	20	0.13
Dec. 3†	107,000	21,600	202	60,000	560	61	0.57†	6.4	0.06
Dec. 4†	108,000	16,600	154	20,000	185	54	0.5†	0.2	0.0018

* Before segregation of whey and start of good housekeeping practices.
† After segregation of whey and start of good housekeeping practices.

For purposes of determining waste volumes and pollution loads to establish a basis of design for the treatment plant constructed, the wastes were gaged and sampled during May 27, 28 and December 3 and 4, 1952. Waste volumes and pollution loads found during these investigations are given in Table IV. Variation in waste flow rates gaged during the May investigation are shown in Figure 5.

The volume of waste containing the bulk of the plant milk losses, so-called polluted wastes, varied from about

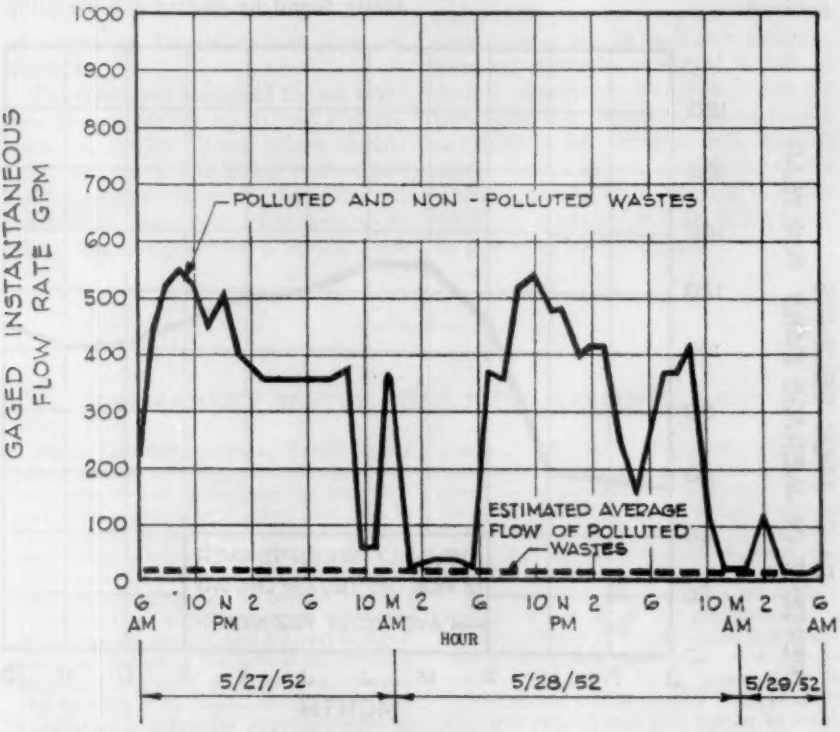

FIGURE 5.—Variations in waste flow rates, Abbotts Dairies, Inc., Belleville, Pa.

17,000 to 27,000 g.p.d., or from 154 to 202 gal. per 1,000 lb. of milk received. In May, prior to whey segregation from wastes discharged from the plant, the B.O.D. content of the polluted wastes amounted to 180 lb. per day, or about 2.35 lb. per 1,000 lb. of milk received. In December, after the discharge of whey with other wastes was discontinued, the whey being segregated and given to farmers for livestock feeding, the B.O.D. content of the polluted wastes ranged from 154 to 202 lb. per day, equivalent to 0.5 and 0.57 lb. per 1,000 lb. of milk received, respectively.

In volume the unpolluted wastes varied from 20,000 to 384,000 g.p.d., equivalent to from 185 to 2,560 gal. per 1,000 lb. of milk received. B.O.D. content of the unpolluted wastes ranged from 0.2 to 26 lb. per day, or from 0.0018 to 0.17 lb. per 1,000 lb. of milk received.

In order to determine the capacity of treatment plant required, daily milk receipts for each month in 1952 were plotted as a function of the average daily receipts for the year, as shown in Figure 6. Minimum and maximum receipts, compared to average receipts, amounted to 60 and 130 per cent, respectively.

The Pennsylvania Sanitary Water Board has adopted standards developed in cooperation with the Pennsylvania Association of Milk Dealers, Inc. These standards indicate the average B.O.D. content of wastes from each operation in a milk plant where an average degree of "conservation" or so-called "good housekeeping" is practiced. The B.O.D. load computed for the December 1952 operations at the Abbotts plant from state standards and a comparison with B.O.D. loads actually found by gaging and sampling

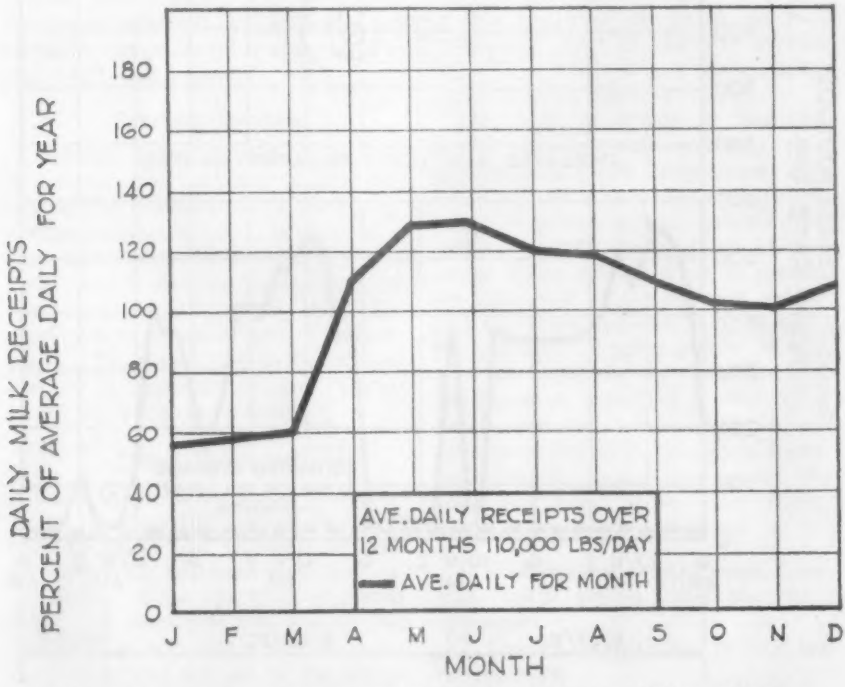

FIGURE 6.—Season trends in milk receipts, Belleville plant, Abbotts Dairies.

TABLE V.—Comparison of Actual Pollution Loads with Those Computed from State Standards, Abbotts Dairy

Process	B.O.D. (lb./day)*	
	Dec. 3, 1952	Dec. 4, 1952
Receiving and cooling	69.2	69.8
Tank truck to and from plant	5.3	7.7
Storing in tank	1.2	2.7
Evaporating whole milk:		
Floor waste	7.8	—
Entrainment loss	3.9	—
Cream separating	—	8.4
Cream pasteurization, cooling, and can filling	14.0	8.4
Cottage cheese making	5.6	—
Milk pasteurization, cooling, and bottling	11.5	12.0
Total poll. load computed from standards	118.5	109.3
Total poll. load by sampling and analysis	67.4	54.2

* From standards of the Pennsylvania Sanitary Water Board.

of wastes in December are given in Table V.

The plant was designed for an average flow of 30,000 g.p.d. and a maximum of 200,000 g.p.d. Plant design provided for a maximum milk waste load estimated from the handling of 150,000 lb. per day. The treatment plant was designed for a B.O.D. load of 325 lb. per day, which indicates a waste of 1,300 p.p.m. B.O.D., or a population equivalent of 1,950 persons. Design was based on a suspended solids load of 160 lb. per day, or a concentration of 640 p.p.m., calculated to be a population equivalent of 800. The volumes and pollution loads adopted for design are given in Table II.

The design factors for each of the treatment units are given in Table III. In general they concur with those adopted for the Borden plant. Because of the greater concentration of B.O.D., the B.O.D. loading was lower for the Abbotts plant.

Cost of Waste Treatment Plants

The Borden waste treatment plant was constructed at a cost of about $100,000, and the Abbotts plant at a cost of about $70,000. Annual operating costs were estimated at $4,000 and $2,500 per year, respectively. The construction cost in each case amounts to about $200 per pound of B.O.D. of design capacity. The total cost of treatment is estimated at about $0.055 per 1,000 lb. of maximum milk handled at the Borden plant, and $0.148 at the Abbotts plant. This amounts to about $0.07 per pound of B.O.D. in the waste as provided for by design.

PERMANENT WATER POLLUTION CONTROL LAW

Public Law 660, known as S. 890 during recent months of Congressional consideration, extends and strengthens the first Federal Water Pollution Control Act (P. L. 845) enacted in 1948, and creates a permanent water pollution control statute.

The new law has broadened and strengthened the preceding law in several respects —particularly with respect to research, state program grants, and Federal enforcement of pollution on interstate streams. Increased emphasis is placed on research and training, both public and private. Authorization is given for appropriations up to $3 million per year for five years for grants to the states for water pollution control programs. The course of action by the Federal government in abating pollution on interstate streams is outlined and strengthened legally while still properly preserving the areas of Federal, state, and local responsibility.

A new feature of the law is the authorization of construction grants-in-aid to municipalities for sewage treatment facilities totaling $50 million a year for 10 years. The grant funds expected to be appropriated will be limited in amount for any one project and will not be available to all communities.

Stream Pollution

SOME EXPERIMENTS ON THE TOXICITY OF COMPLEX CYANIDES TO FISH

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Introduction

The cyanide radical and some of the heavy metals are important constituents of toxic industrial effluents which frequently have destroyed aquatic life in receiving waters. In effluents in which they are normally present together, such as metal-finishing or electroplating plant wastes, they occur often as complex cyanides. Yet, very little is known about the lethality of the various complexes to fish. Students of fish toxicology usually have given attention only to the simple alkali metal cyanides and salts of the heavy metals, evaluating the individual toxicity of each. Even chemical knowledge concerning the complex cyanides formed when solutions of these salts are combined is still quite limited.

The great toxicity of free cyanide to fish has been amply demonstrated. Karsten (1) and Herbert and Merkens (2) have shown that concentrations well below 0.1 p.p.m. as CN^- (0.05 to 0.07 p.p.m.) can be fatal to trout held in continually renewed cyanide solutions. It has long been known that ferrocyanide and ferricyanide ions are comparatively harmless to fish. However, Burdick and Lipschuetz (3) have reported that very dilute potassium ferrocyanide and ferricyanide solutions (for example, 2 p.p.m. as salt) can soon become highly toxic to fish upon exposure to sunlight, because of liberation of cyanide through rapid photo-decomposition of the otherwise stable complexes. The toxicity of relatively concentrated solutions of the salts in diffuse light and in the dark was ascribed to the formation of cyanide ion at a much slower rate. Jones (4) noted that complex salts appear to be generally less toxic than simple salts containing the same elements. The literature on the toxicity to fish of the various metals, as salts, has been reviewed recently by Doudoroff and Katz (5).

Interest in the toxicity of various complex cyanides to fish has been stimulated by the publication of a paper by Milne (6), wherein combination with nickel was proposed as a practical method of detoxification of waste cyanide in dilute solutions. It was suggested that only *free* cyanide be considered in establishing limits of cyanide concentration in industrial effluents and receiving waters, in connection with the regulation of waste disposal. The chemistry of complex formation was outlined, and the concentrations of "free cyanide ion" available from the dissociation of the nickelocyanide complex in solutions of varying concentration, with and without excess nickel, were computed.

Milne asserted that the appearance of a precipitate upon the addition of a nickel salt to a solution initially containing free cyanide (with or without any of the various complex cyanides

which occur in metal-finishing plant wastes) indicates that practically no free cyanide remains. The remaining complex cyanides can be disposed of safely, in his opinion, without endangering fish life in any receiving water which is not rendered exceedingly acid by pollution with strongly acid wastes (which may decompose the complexes). Milne evidently believed that the dissociation not only of the nickelocyanide complex, $Ni(CN_4)^=$, but also of the other metal-cyanide complex ions, is negligible in dilute solutions with pH within the usual pH range of natural waters. While realizing that some dissociation must occur, he thought it is "immediately evident" that "as long as the cyanide ion can be kept bound up in a complex, the amount of free cyanide ion in solution should be below the limits of toxicity as presently conceived." Nickel was selected as the most suitable metal for combination with excess free cyanide in dilute electroplating plant wastes (rinse waters) not for toxicological reasons, but for other, mostly economic reasons.

An experiment was reported wherein young goldfish were exposed to a solution of sodium cyanide to which nickel sulfate had been added. The total cyanide content of the solution was determined to be 104 p.p.m. (by distillation), the nickel content 77 p.p.m., and the pH 8.1. It was reported that the goldfish were not noticeably affected after a 24-hr. exposure. With the exception of this single observation, the study was purely theoretical.

Very recently, when this paper was in the last stages of preparation, Lipschuetz and Cooper (7) published some interesting data on the toxicity of potassium cuprocyanide to blacknose dace. They found that KCN solutions were about two to four times as toxic as some cuprocyanide solutions with corresponding total cyanide content prepared by dissolving cuprous cyanide in KCN solutions. The toxicity of these cuprocyanide solutions (in tap water at pH 7.6 to 8.0) decreased as the ratio of gram moles of total cyanide (CN^-) to gram atoms of copper decreased from 4.0 to 3.0.

Although the author could not admit the validity of some of the premises on which theoretical conclusions published in the past were based, it was apparent that the practical suggestions of Milne (6) have some merit. The investigation reported herein was undertaken in order to determine whether effective detoxification of cyanide solutions and solutions of certain heavy metal salts can or cannot be achieved through their combination, and what are the specific conditions for such reduction of toxicity. The practical objectives of the study were to define the value of complex formation as a waste treatment method, and to establish a factual basis for the regulation of the disposal of wastes containing complex cyanides.

Material and Methods

Experimental Fish

The fish used were young fathead minnows, *Pimephales promelas* Rafinesque, averaging about 5 cm. in total or over-all length (range 44 to 57 mm.) and slightly over 1 g. in weight. They had been reared in ponds of the Ohio State Fish Farm at Newtown, Ohio, supplied with hard spring water. The fish were stocked in the laboratory in large glass aquaria supplied with Cincinnati, Ohio, municipal tap water (treated Ohio River water), which had been passed through an activated carbon filter to remove residual chlorine. These aquaria were kept in a 20° C. constant-temperature room, where the experiments were performed also. The water was aerated continuously with compressed air and renewed periodically. The fish were fed ground dog biscuit and remained apparently in good condition for many months.

Experimental Water

A soft water with a low and uniform dissolved mineral content was desired

for use as a diluent in the preparation of most of the experimental solutions of chemicals tested. Inasmuch as the experiments were planned without reference to any specific, local waste disposal problem, the use of no particular natural water was indicated. However, waters with high or variable concentrations of dissolved minerals which may counteract the toxicity of substances tested, or entirely lacking dissolved minerals known to be physiologically important, were not deemed appropriate. No suitable natural water having been available, a synthetic soft water was prepared by adding reagent-grade salts to distilled water from tin-lined stills.

First, a clear solution of calcium bicarbonate was prepared by bubbling dispersed carbon dioxide gas through a suspension of calcium carbonate, containing 210 mg. $CaCO_3$ per liter, in distilled water. One liter of this solution was diluted with 11 l. of distilled water, and 3 ml. of a mixed salt solution containing 0.4 mole NaCl, 0.3 mole $MgSO_4$, and 0.025 mole K_2SO_4 per liter were added. The excess CO_2 was then removed by gentle overnight aeration of the mixture with dispersed air. The concentration of each added ion in the experimental water so prepared (7 p.p.m. Ca^{++}, 1.8 p.p.m. Mg^{++}, 2.3 p.p.m. Na^{+}, 0.5 p.p.m. K^{+}, 21.3 p.p.m. HCO_3^{-}, 7.8 p.p.m. $SO_4^{=}$, and 3.5 p.p.m. Cl^{-}) is approximately one-fourth its average (median) concentration in stream waters of the United States (8). The concentrations of added Ca^{++}, Mg^{++}, and HCO_3^{-} ions correspond to a total hardness of 25 p.p.m. as $CaCO_3$ and a total alkalinity, or carbonate hardness, of 17.5 p.p.m. as $CaCO_3$.

For experiments in which it was necessary to vary the mineral content and pH of the water and test solutions, other waters with the desired characteristics (total alkalinity and hardness from 5 to 192 p.p.m. and from 7 to 275 p.p.m. as $CaCO_3$, respectively) were prepared likewise. The volumes of the two stock salt solutions used in making up 12 l. of water were reduced or increased proportionately, as necessary. Unless otherwise designated when test results are reported, the experimental water used was the soft water first described.

Fish kept in the experimental waters (controls) remained apparently in good health indefinitely. Comparative tests of the toxicity of the various chemicals studied have been performed using waters prepared with ordinary distilled waters from two tin-lined stills and with a triple-distilled water of high purity (redistilled in glass first from H_2SO_4—$K_2Cr_2O_7$—Ag_2SO_4 solution, and then from NaOH solution). These tests showed that the slight contamination of the ordinary distilled waters with impurities known to have been present did not invalidate the conclusions reported herein.

Experimental Procedures and Conditions

The experimental waters just described were used for diluting mixed solutions the toxicity of which was to be evaluated. These solutions were prepared usually by adding distilled water solutions of sulfates of different heavy metals, containing 1,000 p.p.m. of metal, to agitated solutions of sodium cyanide, also in distilled water, with a cyanide content of about 930 to 950 p.p.m. as CN^{-}, determined by titration with silver nitrate, using rhodanine indicator (9). In some experiments the simple solutions so combined were more concentrated or less concentrated, and in a few tests the NaCN and metal sulfate solutions were added to the experimental water without previous mixing. With some exceptions to be noted, the undiluted mixed solutions were unquestionably turbid, but did not contain large amounts of precipitated metal cyanides, hydroxides, or other insoluble compounds. When the amount of metal salt introduced was just suffi-

cient to produce the slight turbidity, nearly all the cyanide and metal present obviously remained in solution, mostly as soluble complex cyanide. Solutions of purified complex cyanides were used only in a few tests.

The test animals were always held for two days without food in the experimental water (diluent) before being exposed to the test solutions. Inasmuch as they were already thoroughly acclimatized to laboratory conditions and the experimental temperature (20° C.), and in view of the purpose of the toxicity tests, more prolonged acclimatization of the fish to the experimental water was not deemed necessary.

With regard to other features, the toxicity bioassay procedure was essentially the standardized routine procedure for the evaluation of acute toxicity of industrial wastes to fish described by Doudoroff *et al.* (10) The experimental vessels were cylindrical Pyrex glass jars 12 in. in diameter and 12 in. high. Five test animals were placed in each jar, containing 12 l. of experimental solution, the depth of which was about 7 in. Each important test was performed at least twice, using a total of at least 10 test animals. The fish were not fed during the tests.

The number of test animals surviving at each one of a series of experimental concentrations of the toxicant tested was recorded 24 hr., 48 hr., and 96 hr. after the beginning of each test, and sometimes after other exposure periods up to 10 days. The median tolerance limit (TL_m), or the concentration which is fatal to just 50 per cent of the test animals, for each of the specified exposure periods, was estimated by straight-line graphical interpolation (10).

The experimental solutions usually were not aerated artificially. Numerous determinations of the dissolved oxygen content, which was initially near the saturation value, showed that it declined gradually during the first 48 hr. or so. It remained thereafter usually in the neighborhood of 5 or 6 p.p.m. as long as most of the test animals remained alive, and it was always well above 4 p.p.m. With certain exceptions to be noted, the experimental solutions were nearly neutral in reaction, most of them being so dilute that the chemicals added to the somewhat buffered experimental water had no appreciable influence on the pH. The pH values declined slightly during the first two days or so, because of accumulation of respiratory free CO_2 produced by the fish, but remained within the range from 7.5 to 6.5 throughout the tests. The temperature ranged from 19.5° to 20.5° C.

In a series of special experiments on the influence of pH upon the toxicity of the nickelocyanide complex, the procedure was modified to ensure desired uniformity of pH and dissolved oxygen throughout each test. The test animals, not fed for two days, were placed in test jars containing 12 l. of experimental water (diluent) of appropriate, varying total alkalinity and hardness. Two days later, when the pH of the water was nearly constant, the concentrated solution of toxicant was added to each jar, after removing an equal volume of water. Any resulting increase of pH was promptly compensated for by adding a little CO_2 solution, prepared with a small portion of the diluent withdrawn previously for this purpose. To avoid exposure of the test animals to the high pH of the more concentrated dilutions before their neutralization with CO_2, the fish were temporarily removed from the test jars before the introduction of toxicant, and returned as soon as the pH had been adjusted. The pH was recorded at daily intervals during the tests, and sometimes oftener. Reduction of the rate of production of CO_2 by the fasting fish often resulted in a gradual rise of the pH of test solutions, especially after the death of a few fish. In a few instances in which

this rise was deemed sufficiently important, the pH was readjusted from time to time by the addition of a little CO_2.

The recorded pH values were determined electrometrically, using a glass electrode. They were consistently slightly higher (by about 0.1 to 0.2 pH unit) than corresponding values determined colorimetrically. Although they may not be absolutely correct, they are believed to represent the hydrogen ion concentrations of the various solutions accurately enough for present, chiefly comparative, purposes.

In addition to determination of comparable median tolerance limits under experimental conditions already described, various experiments designed to throw light on specific problems which arose in the course of the investigation were performed. The special techniques employed in conducting these supplementary tests are described briefly along with the results in the following section.

Experimental Results

Sodium Cyanide

The results of an evaluation of the toxicity of NaCN alone under the experimental conditions described, which was performed as the first step for comparative purposes, are shown in Table I. These results have been compared with other similar data reported in available literature (to be reviewed fully in another publication). It was concluded that the fish used in this study are neither unusually resistant nor outstandingly susceptible to cyanide.

It is noteworthy that fish which did not die within 24 hr. usually survived for 96 hr. Complete recovery of some fish which had been markedly affected, even losing equilibrium, at low cyanide concentrations (for example, 0.24 p.p.m. as CN^-) was noted. Gradual reduction of the toxicity of the test solutions in the course of the tests, which is suggested by these observations, was demonstrated experimentally. Five fish were placed in each of two jars containing 12 l. of fresh NaCN solution with initial concentration of 0.32 p.p.m. as CN^-. All 10 were dead within 14 hr. When the solutions were 24 hr. old, five fish again were placed in each jar, the dead fish having been removed. Of the 10 new fish, 8 lived for 15 hr. and 4 (2 in each jar) were still alive and active 48 hr. and 72 hr. after their introduction. These fish having been removed, five new test animals then were placed in each jar with the 96-hr. old solutions. All were alive and apparently healthy after 48 hr. The loss of cyanide from the test solutions, in which it occurs mostly as volatile HCN, evidently is sufficiently rapid to influence markedly the results of toxicity tests performed without renewal of test solutions, such as those reported in Table I.

TABLE I.—Toxicity of Sodium Cyanide in Soft Water to *Pimephales promelas* at 20° C.

Cyanide, as CN^- (p.p.m.)[1]	Number of Tests	Number of Fish	Fish Surviving (%)		
			24 Hr.	48 Hr.	96 Hr.
0.42	2	10	0	0	0
0.32	2	10	0	0	0
0.24	3	15	60	53	40
0.18	2	10	100	100	90
0.135	2	10	100	100	100
0.10	2	10	100	100	100
Control	4	20	100	100	100
Est. median tolerance limits, TL_m [2], in p.p.m. cyanide, as CN^-			0.25	0.24	0.23

[1] Cyanide ion equivalent of total added cyanide (initial concentration).

[2] Each median tolerance limit shown is the estimated TL_m for the exposure period (in hours) heading the column.

The initial results shown in Table I were checked later, using soft experimental waters prepared with ordinary distilled and triple-distilled waters. Again, all the fish were killed within 24 hr. by 0.32 p.p.m. of cyanide (as CN^-), and 90 per cent of the fish tolerated 0.18 p.p.m. (initial concentra-

tion) for 96 hr. In harder water (total alkalinity 70 p.p.m. as $CaCO_3$) 0.4 p.p.m. proved fatal to all fish within 16 hr. at pH 8.2 to 8.0. Lower concentrations were not tested.

Zinc Cyanide Complex (NaCN *with* $ZnSO_4$)

The toxicity of a fresh mixed solution of NaCN and $ZnSO_4$ containing about 564 p.p.m. of cyanide (as CN^-) and 394 p.p.m. of zinc was evaluated in the usual manner. The ratio of zinc to cyanide by weight was 0.7. The corresponding ratio for the $Zn(CN_4)^=$ ion is 0.63. The undiluted mixed solution was alkaline and gradually became decidedly turbid, but a pronounced odor of HCN persisted. The results of the toxicity tests are presented in Table II.

The estimated median tolerance limits expressed as p.p.m. of total cyanide are all considerably lower than the corresponding values obtained with NaCN alone. Cyanide solutions evidently are not effectively detoxified by the addition of zinc salts in quantity insufficient for precipitation of much of the cyanide as insoluble zinc cyanide. On the contrary, the toxicity apparently was aggravated in the presence of zinc. The toxicity of zinc sulfate alone is not sufficient to account for the great toxicity of the mixture tested. As much as 1 p.p.m. as Zn could be tolerated by all the test animals for more than four days in the experimental water used, and even much higher concentrations, far above the limit of tolerance, were not very rapidly effective. The behavior of the fish in the toxic test solutions containing cyanide with zinc, and the speedy lethal action of the combined toxicants at concentrations only slightly above the limit of tolerance, were suggestive of cyanide poisoning.

Great toxicity of the NaCN-$ZnSO_4$ mixture diluted with fairly hard and alkaline water (total alkalinity 70 p.p.m. as $CaCO_3$; pH 8.2 to 8.0), as well as with ordinary experimental water, was demonstrated by additional tests performed later. It was evident that the toxicity of the zinc cyanide complex was not greatly reduced in the more alkaline water.

A few tests were performed using a purified potassium zinc cyanide prepared by F. J. Ludzack in the manner described in a recent paper (9) and dissolved in ordinary experimental water. These tests yielded further evidence of the high toxicity of the zinc cyanide complex. In two parallel tests, 1.0 p.p.m. of the complex salt, which corresponds to about 0.4 p.p.m.

TABLE II.—Toxicity of a Mixed Solution of Sodium Cyanide (564 p.p.m. as CN^-) and Zinc Sulfate (394 p.p.m. as Zn), Diluted with Soft Water, to *Pimephales promelas* at 20° C.

Concentration by Volume (%)	Cyanide, as CN^- (p.p.m.)[1]	Zinc (p.p.m.)	Number of Tests	Number of Fish	Fish Surviving (%)		
					24 Hr.	48 Hr.	96 Hr.
0.057	0.32	0.22	2	10	0	0	0
0.043	0.24	0.17	2	10	10	10	10
0.032	0.18	0.125	2	10	80	60	50
0.024	0.135	0.095	2	10	100	100	90
Control	—	—	2	10	100	100	100
Est. median tolerance limits, TL_m[2]: Per cent by volume					0.036	0.034	0.032
P.p.m. cyanide, as CN^-					0.20	0.19	0.18

[1] See Table I, Note 1.
[2] See Table I, Note 2.

TABLE III.—Toxicity of a Mixed Solution of Sodium Cyanide (439 p.p.m. as CN^-) and Cadmium Sulfate (528 p.p.m. as Cd), Diluted with Soft Water, to *Pimephales promelas* at 20° C.

Concentration by Volume (%)	Cyanide, as CN^- (p.p.m.)[1]	Cadmium (p.p.m.)	Number of Tests	Number of Fish	Fish Surviving (%)		
					24 Hr.	48 Hr.	96 Hr.
0.091	0.40	0.48	2	10	0	0	0
0.064	0.28	0.34	2	10	0	0	0
0.046	0.20	0.24	2	10	80	60	40
0.032	0.14	0.17	2	10	100	80	60
0.023	0.10	0.12	2	10	100	100	100
Control	—	—	2	10	100	100	100
Est. median tolerance limits, TL_m[2]: Per cent by volume					0.052	0.048	0.038
P.p.m. cyanide, as CN^-					0.23	0.21	0.17

[1] See Table I, Note 1.
[2] See Table I, Note 2.

of total cyanide (as CN^-), killed all the fish within 18 hr.

Cadmium Cyanide Complex (NaCN *with* $CdSO_4$)

The toxicity of a fresh mixture of NaCN and $CdSO_4$ solutions, containing 439 p.p.m. of cyanide (as CN^-) and 528 p.p.m. of cadmium, was evaluated in the usual manner. The cadmium-to-cyanide weight ratio was 1.2. Although the corresponding ratio for the $Cd(CN_4)^=$ ion is only 1.08, the mixed solution remained clear. In view of the high solubility of cadmium cyanide, no precipitation of $Cd(CN)_2$ was to be expected. The results of the toxicity tests are presented in Table III.

These results correspond closely with those obtained when cyanide was combined with zinc. Dilutions of the NaCN-$CdSO_4$ mixed solution proved as toxic as comparable NaCN solutions with considerably higher cyanide content. Their high toxicity is not attributable simply to that of cadmium, which is somewhat more toxic than zinc. The results of tests with $CdSO_4$ alone were somewhat variable, but most of the fish withstood 0.34 p.p.m. as Cd for 96 hr. At least four of five test animals survived at this concentration for 24 hr. in each of three tests.

Nickel Cyanide Complex (NaCN *with* $NiSO_4$)

Data on the toxicity of a fresh mixed solution of NaCN and $NiSO_4$, in which about 600 p.p.m. of cyanide (as CN^-) had been combined with 355 p.p.m. of nickel, are presented in Table IV. The weight ratio of nickel to cyanide was 0.59. The corresponding ratio for the $Ni(CN)_4^=$ ion is 0.56. The undiluted solution was very alkaline, yellow, and somewhat turbid, containing a small amount of flocculent precipitate, and had no detectable odor of HCN. The tests were performed in the usual manner. Complete records of the changing pH of the test solutions were not made, but it was noted that the three highest concentrations tested were associated with pH initially well above 9.0.

The test solutions with concentrations equivalent to 200 and 350 p.p.m. of cyanide (as CN^-) and initial pH above 9.0 proved much less rapidly fatal than much more dilute, nearly neutral solutions with concentrations equivalent to only 4 to 16 p.p.m. of cyanide. In tests of intermediate concentrations (23 to 67 p.p.m. as CN^-), which are not shown in Table IV, most of the fish survived for 24 hr., but all died within 96 hr. Thus, two 48-hr. median tolerance limits, a lower "pri-

TABLE IV.—Toxicity of a Mixed Solution of Sodium Cyanide (600 p.p.m. as CN^-) and Nickelous Sulfate (355 p.p.m. as Ni), Diluted with Soft Water, to *Pimephales promelas* at 20° C.

Concentration by Volume (%)	Cyanide, as CN^- (p.p.m.)[1]	Nickel (p.p.m.)	Number of Tests	Number of Fish	Fish Surviving (%)			
					24 Hr.	48 Hr.	96 Hr.	168 Hr.
100.0	600	355	2	10	0	0	0	0
58.3	350	207	2	10	100	40	10	0
33.3	200	118	2	10	100	90	0	0
2.67	16.0	9.5	2	10	80	0	0	0
1.33	8.0	4.7	2	10	100	0	0	0
0.67	4.0	2.4	2	10	100	10	0	0
0.47	2.8	1.7	2	10	100	30	0	0
0.33	2.0	1.2	2	10	100	90	10	10
0.167	1.0	0.59	3	15	100	93	47	33
0.083	0.50	0.30	2	10	100	100	90	60
0.042	0.25	0.15	2	10	100	100	100	100
Control	—	—	4	20	100	100	100	100
Estimated secondary TL_m[2]: Per cent by volume					76	52	—	—
P.p.m. cyanide, as CN^-					460	310	—	—
Estimated primary TL_m[2]: Per cent by volume					—	0.42	0.16	0.11
P.p.m. cyanide, as CN^-					—	2.5	0.95	0.65

[1] See Table I, Note 1.

[2] See Table I, Note 2. For explanation of the meaning of primary and secondary median tolerance limits (TL_m) see text.

mary'' one and a higher ''secondary'' one, were estimated, but no 24-hr. TL_m comparable to the primary 48-hr. TL_m, and no 96-hr. TL_m comparable to the secondary 48-hr. TL_m, could be reported. The median tolerance limits shown in Table IV have been classified accordingly. Cyanide combined with nickel evidently was less toxic than free cyanide, especially at high concentrations, but all test concentrations of the mixture above 0.25 p.p.m. as CN^- proved demonstrably toxic.

A relatively concentrated NaCN-$NiSO_4$ mixed solution, wherein about 5,150 p.p.m. of cyanide (as CN^-) had been combined with 2,940 p.p.m. of nickel, was tested later. The nickel-to-cyanide weight ratio being 0.57, this solution contained very little precipitate. The results are shown in Table V. They agree essentially with the earlier results, but the test concentration equivalent to 23 p.p.m. of cyanide proved fatal to most of the fish in 24 hr. The existence of both a primary 24-hr. TL_m (between 200 and 600 p.p.m. as CN^-), and a secondary 24-hr. TL_m (between 8 and 23 p.p.m. as CN^-), as well as a primary and a secondary 48-hr. TL_m, is indicated. Because of wide intervals between the concentrations tested, the TL_m values could not be accurately estimated.

Nickel sulfate alone in concentration equivalent to 100 p.p.m. of nickel killed all the fish within 24 hr. in two tests. However, 13.6 p.p.m. as Ni killed no fish in 48 hr., one of 10 fish in 96 hr., and only 5 of 10 fish in 6 days; and 1.67 p.p.m. as Ni had no effect in six days.

In experiments with some available purified potassium nickelocyanide, prepared by F. J. Ludzack in the manner described in a recent publication (9), 5 p.p.m. of the complex salt, or approximately 2 p.p.m. as CN^-, killed 9 of 10 fish within 96 hr., but none in 48 hr. This result agrees well with the

TABLE V.—Toxicity of a Mixed Solution of Sodium Cyanide (5,150 p.p.m. as CN^-) and Nickelous Sulfate (2,940 p.p.m. as Ni), Diluted with Soft Water, to *Pimephales promelas* at 20° C.

Concentration by Volume (%)	Cyanide, as CN^- (p.p.m.)[1]	Nickel (p.p.m.)	Number of Tests	Number of Fish	Fish Surviving (%)			
					24 Hr.	48 Hr.	96 Hr.	168 Hr.
11.65	600	343	1	5	0	0	0	0
3.88	200	114	2	10	100	80	0	0
1.30	67	38	2	10	80	0	0	0
0.45	23	13	2	10	20	0	0	0
0.155	8.0	4.6	2	10	100	0	0	0
0.039	2.0	1.15	2	10	100	100	0	0
0.0097	0.50	0.29	2	10	100	100	100	80
Control	—	—	2	10	100	100	100	100

[1] See Table I, Note 1.

results of tests of diluted $NaCN$-$NiSO_4$ mixed solutions with corresponding total cyanide content shown in Tables IV and V.

When NaCN and $NiSO_4$ were combined in the experimental water in amounts equivalent to 0.5 p.p.m. of cyanide (as CN^-) and 0.3 p.p.m. of nickel, respectively, and fish were introduced 1 hr. later (two tests), all of 10 fish lived for 48 hr., 9 lived for 96 hr., and 7 survived for 168 hr. The formation of nickelocyanide complex, resulting in reduced toxicity of the cyanide, evidently occurs promptly in such very dilute mixed solutions, as well as in more concentrated mixtures.

Exposure of a diluted $NaCN$-$NiSO_4$ mixed solution (like those used in the initial series of tests) to bright, outdoor sunlight during the first 6 hr. of the first and second days of a toxicity test (early in May) did not result in any increase of toxicity. The temperature was held near 20° C. by immersing the directly illuminated test jars in cool running tap water. The survival time of 10 experimental fish in these jars averaged somewhat longer than that of 10 controls exposed to the same concentration of the toxic mixture (6 p.p.m. as CN^-) in subdued light in the constant-temperature room.

Although nickel and cyanide ions form a complex readily in very dilute mixed salt solutions, and photo-decomposition of the complex could not be demonstrated, there was evidence of gradual decomposition of the complex in the course of toxicity tests. The toxicity of the test solutions seemed to increase with time, and they acquired a perceptible odor of HCN, which was lacking initially and suggested liberation of cyanide.

Various experiments were performed in order to verify the supposition that the toxicity of the test solutions increased during the tests, and to establish the cause of this increase. Diluted $NaCN$-$NiSO_4$ mixed solutions with concentration equivalent to 8 p.p.m. of cyanide (as CN^-) and a nickel-to-cyanide ratio of 0.57 were used in all of these experiments. In these solutions the test animals often began to show distress (though none died) within 20 hr., and they invariably succumbed within 40 hr. if the solutions were not renewed or treated in any way. However, affected fish recovered promptly and all fish lived for more than 40 hr. when they were transferred to a fresh solution after the first 20 hr. The fresh solution could be one which had just been prepared, or one prepared at the same time as the initial test solution and stored until needed in a jar without fish. When the test solution was renewed twice, about 21 and 42 hr. after the beginning of the test, all the fish were normal after 48 hr.

and most of them lived for 72 hr. A two-day old solution in which five fish already had died killed all of five additional test animals in less than 20 hr. On the other hand, a solution which had been stored for two days in a full, stoppered carboy without fish killed no fish in 20 hr. The toxicity of the solutions evidently increased markedly with time in the presence of test animals only. Solutions stored without fish remained odorless.

The addition of a small amount of nickel sulfate (0.2 p.p.m. as Ni) to the test solution 20 hr. after the introduction of fish did not prolong the survival of the fish. The addition of oxygen (by dilution of the test solution with a small amount of water saturated with pure oxygen) to restore the initial dissolved oxygen concentration after 20 hr. also had no significant effect. On the other hand, when the pH of the test solutions was raised by about one-half of one pH unit to the initial value by the addition of NaOH, affected fish recovered promptly and all lived for more than 40 hr. By readjusting the pH repeatedly with NaOH, all the fish were kept alive for 60 hr. The addition of enough CO_2 to render the test solution faintly acid at the beginning of a test markedly increased the toxicity of the solution. The addition of a little NH_4Cl (1.0 p.p.m. as NH_3) had no appreciable effect. When the test solutions were prepared with hard waters of such high total alkalinity that the pH of the solutions did not fall much below 7.5 at any time during the tests, all the fish lived for 10 days.

It is apparent that the observed gradual increase of the toxicity of the test solutions in the presence of fish is not attributable to reduction of the dissolved oxygen concentration, nor to withdrawal of nickel from the solution by the fish (with liberation of cyanide), nor to accumulation of metabolic ammonia. The increase of toxicity was evidently due, instead, to the accumulation of respiratory CO_2 and the resulting slight reduction of pH, by as little as 0.5 pH unit. In the light of theoretical analysis of the ionic equilibria involved, which are to be discussed later, the reason for the very striking influence of such small changes of pH became apparent. The prolonged survival of test animals in relatively concentrated test solutions (Tables IV and V) was clearly ascribable to the high initial pH.

The relation between pH and the toxicity of the nickel cyanide complex was investigated more thoroughly later. Experimental waters of varying total alkalinity and hardness were used, and nearly constant pH values were achieved and maintained by procedures already described. The concentration of the $NaCN$-$NiSO_4$ mixed solutions used in the preparation of more dilute test solutions was equivalent to about 5,150 p.p.m. of cyanide (as CN^-), and the weight ratio of nickel to cyanide was about 0.57. The pH of each test solution was determined at the beginning of the test, and thereafter at daily intervals or oftener. The daily average pH thus could be estimated. The mean of successive daily averages was taken to be the average pH for each exposure period of more than one day.

The toxicity of the mixture tested at each of five pH values ranging from about 6.5 to 8.0 was evaluated. Two or three tests of each appropriate concentration of toxicant were performed first with diluent water of lowest total alkalinity and pH, and then with waters of progressively increasing alkalinity and pH. Subsequent additional tests with waters of decreasing alkalinity and pH revealed no change of the resistance of the fish to alkaline solutions, but a slight, unexplained decrease of their resistance to neutral and acid solutions was noted. Therefore, all of the earlier tests of neutral and acid solutions were repeated. The survival percentages reported in Table

TABLE VI.—Toxicity of a Mixed Solution of NaCN (5,150 p.p.m. as CN^-) and $NiSO_4$ (2,940 p.p.m. as Ni), Diluted with Waters of Varying Total Alkalinity, to *Pimephales promelas* at 20° C. and Adjusted pH[1]

Total Alkalinity of Diluent Water, as $CaCO_3$ (p.p.m.)[2]	Cyanide, as CN^- (p.p.m.)[3]	Number of Tests	Number of Fish	Mean pH[4]	Fish Surviving (%)		
					24 Hr.	48 Hr.	96 Hr.
5	2.0	4	20	6.5–6.6	25	0	0
5	1.0	6	30	6.5–6.6	70	27	7
5	0.50	6	30	6.5–6.6	97	83	33
5	0.25	4	20	6.5	100	100	100
21	8.0	4	20	7.0	0	0	0
21	4.0	6	30	7.0	73	20	3
21	2.0	4	20	7.0	100	60	10
21	1.0	4	20	7.0	100	100	90
70	80	3	15	7.5	40	27	—
70	40	4	20	7.5	60	40	15
70	20	3	15	7.5	100	100	53
70	10	2	10	7.5	100	100	100
122	800	3	15	7.8	27	7	0
122	400	3	15	7.8	80	60	20
122	200	3	15	7.8	100	87	53
122	100	2	10	7.7	100	100	90
192	2,000	2	10	8.0	0	0	0
192	1,000	3	15	8.0	80	67	20
192	500	3	15	8.0	93	93	87

[1] The pH was stabilized, or adjusted with CO_2 to nearly constant values depending on the total alkalinity of the water.

[2] Approximate total alkalinity based on the amount of $CaCO_3$ added to distilled water. The total hardness of the water, expressed as the $CaCO_3$ equivalent in parts per million, is equal to 1.43 times the total alkalinity. Control tests, not recorded in the table, have shown that the test animals could live indefinitely (more than 10 days) in any of the diluent waters used.

[3] Cyanide ion equivalent of total added cyanide (initial concentration). The concentration of each test dilution expressed as per cent by volume is equal to 0.0194 times the concentration of cyanide (as CN^-) in parts per million, and the nickel content in parts per million is 0.57 times the cyanide content shown.

[4] Average pH of test solutions, based on daily or more frequent observations continued until all the fish were dead or the experiment was discontinued. The mean value for the first 24 hr., rounded off to one decimal place, usually did not differ from the corresponding values for longer exposure periods up to and including 96 hr. In the few exceptional cases in which the ultimate (48-hr. or 96-hr.) mean is greater by 0.1 pH unit than the initial 24-hr. mean, both of these values are shown.

VI are means of all the values obtained in the initial and subsequent tests.

The experimental results presented in Table VI, and also in Table VII and Figure 1, show that the fish could withstand more than 1,000 times as much cyanide combined with nickel at pH 8.0 than at pH 6.5. They show also that mere doubling of the hydrogen ion concentration, or reduction of pH by little more than 0.3 pH unit (for example, from 7.8 to about 7.5), can result in more than ten-fold increase of the toxicity of the NaCN-$NiSO_4$ mixture.

An incidental observation of uncertain significance is deemed interesting enough to be recorded here. The bodies of fish exposed to slowly lethal, fairly concentrated, but somewhat alkaline test solutions, frequently became strikingly swollen some time be-

fore the fish died. Other fish in the same solutions were apparently unaffected or died without any such swelling of the body, as did also fish exposed to more rapidly fatal solutions and solutions of lower pH. The body muscles of the swollen fish bulged behind the head, and the entire body often was so distended (seemingly to almost twice the normal bulk) that the scales projected from the body surface. The swelling may have been due to osmoregulatory or exeretory failure. Red blotches, apparently due

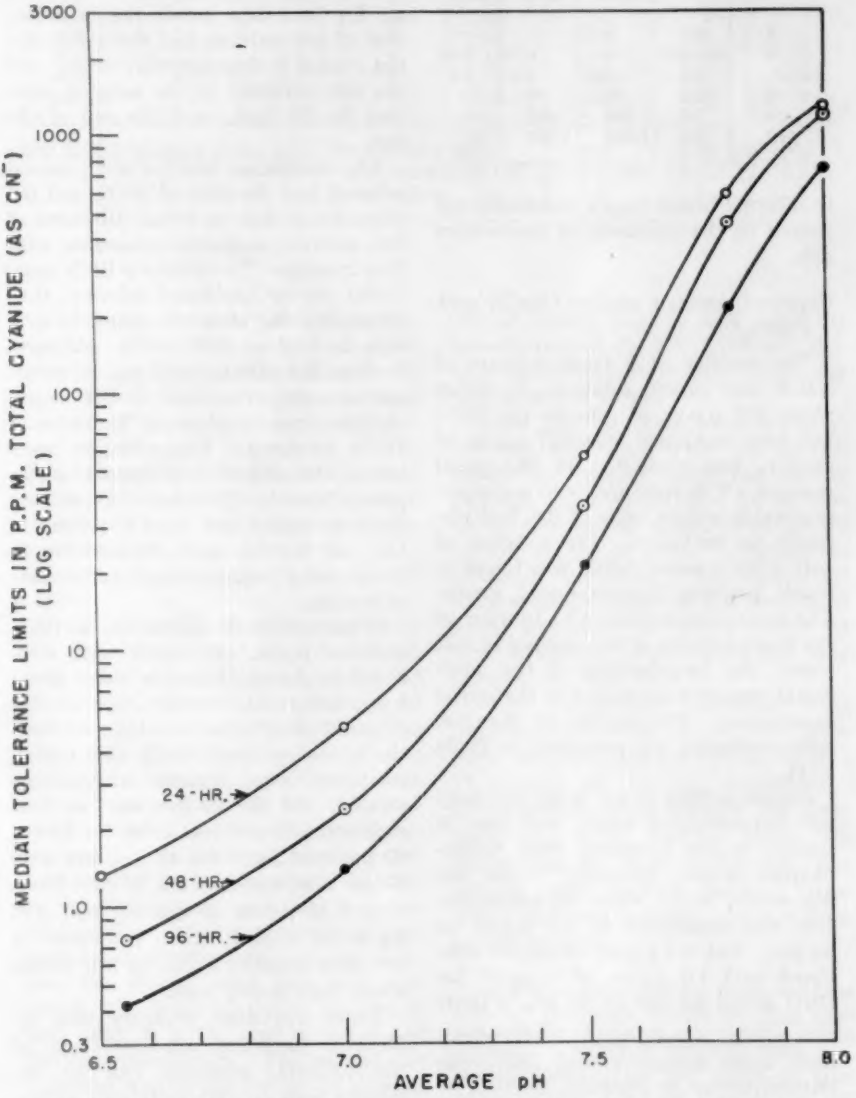

FIGURE 1.—Toxicity of NaCN combined with $NiSO_4$ in relation to pH; data from Table VII.

TABLE VII.—Estimated Median Tolerance Limits (TL_m) of NaCN Combined with $NiSO_4$, Based on Data Presented in Table VI

Total Alkalinity of Diluent Water, as $CaCO_3$ (p.p.m.)	Mean pH	TL_m, cyanide as CN^- (p.p.m.)		
		24 Hr.	48 Hr.	96 Hr.
5	6.5	1.35	—	—
5	6.5–6.6	—	0.75	0.42
21	7.0	5.0	2.4	1.4
70	7.5	56	36	21
122	7.8	590	450	210
192	8.0	1,300	1,200	730

to internal hemorrhages, commonly appeared on the abdomens of the swollen fish.

Copper Cyanide Complex (NaCN *with* $CuSO_4$)

The toxicity of a fresh mixture of NaCN and $CuSO_4$ solutions, in which about 533 p.p.m. of cyanide (as CN^-) had been combined with 427 p.p.m. of copper, was evaluated in the usual manner. This mixture, with a copper-to-cyanide weight ratio of 0.8, had virtually no turbidity. The addition of only a little more $CuSO_4$ was found to result, however, in pronounced, gradually increasing turbidity.* In view of the great toxicity of free copper in soft water, the introduction of the additional copper was avoided in the initial experiment. The results of the toxicity evaluation are presented in Table VIII.

Copper sulfate alone, in the ordinary soft experimental water, and also in similar water prepared with triple-distilled water, invariably killed the fish within 24 hr. when the concentration was equivalent to 0.1 p.p.m. of copper. Yet, 0.8 p.p.m. of copper combined with 1.0 p.p.m. of cyanide (as CN^-) killed no fish in 96 hr. (Table VIII). The same result was obtained when the test solution was exposed to direct sunlight during the first 6 hr. of the test (late in May), keeping the temperature between 20° and 22° C. by immersing the test jar in cool running tap water. Continuous aeration of a similar solution with compressed air for four days before the introduction of test animals and thereafter did not render it demonstrably toxic. All the fish survived in the aerated solution for 10 days, until the end of the test.

The undiluted NaCN-$CuSO_4$ mixed solution had the odor of HCN, and the behavior of fish in lethal dilutions of this mixture suggested poisoning with free cyanide. By adding a little more $CuSO_4$ to the undiluted mixture, thus increasing the ratio of copper to cyanide to 0.82 or 0.85, or by adding a little nickel sulfate (0.05 mg. of nickel for each mg. of cyanide as CN^-), precipitates were produced. The odor of HCN persisted. The solutions were tested with and without removal of the precipitates by filtration. At concentrations equivalent to 4.0 p.p.m. of CN^-, all the fish again died within 24 hr. in every test, seemingly of cyanide poisoning.

When 1.0 p.p.m. of cyanide (as CN^-) and 0.8 p.p.m. of copper were combined in the experimental water about 1 hr. before the introduction of fish (instead of diluting a mixture of relatively concentrated NaCN and $CuSO_4$ solutions) some toxicity was demonstrated. Of the 20 fish used in four such tests, 85 per cent lived for 24 hr., 65 per cent lived for 48 hr., and only 45 per cent survived for 96 hr. However, 0.32 p.p.m. of cyanide and 0.25 p.p.m. of copper, when combined in the same manner, killed no fish within seven days in two tests.

There was some evidence that ordinarily harmless concentrations of NaCN-$CuSO_4$ mixtures can be decidedly toxic in extremely soft waters, especially when the dilute solutions are

* Later observations indicated that NaCN-$CuSO_4$ mixed solutions undergo considerable chemical change on prolonged standing, including solution of small amounts of precipitate initially produced.

TABLE VIII.—Toxicity of a Mixed Solution of Sodium Cyanide (533 p.p.m. as CN^-) and Cupric Sulfate (427 p.p.m. as Cu), Diluted with Soft Water, to *Pimephales promelas* at 20° C.

Concentration by Volume (%)	Cyanide, as CN^- (p.p.m.)[1]	Copper (p.p.m.)	Number of Tests	Number of Fish	Fish Surviving (%)		
					24 Hr.	48 Hr.	96 Hr.
1.50	8.0	6.4	2	10	0	0	0
0.75	4.0	3.2	2	10	0	0	0
0.375	2.0	1.6	2	10	60	50	10
0.187	1.0	0.8	2	10	100	100	100
0.047	0.25	0.2	1	5	100	100	100
Control	—	—	2	10	100	100	100
Est. median tolerance limits, TL_m[2]: Per cent by volume					0.42	0.38	0.28
P.p.m. cyanide, as CN^-					2.2	2.0	1.5
P.p.m. copper					1.8	1.6	1.2

[1] See Table I, Note 1.
[2] See Table I, Note 2.

continuously aerated. Therefore, numerous additional tests were performed, both with and without artificial aeration of test solutions, using diluent waters of varying mineral content. In each of these tests a relatively concentrated $NaCN$-$CuSO_4$ mixed solution with a weight ratio of copper to cyanide near 0.8, prepared in the usual manner, was diluted to a concentration equivalent to 0.5 p.p.m. of copper.

Ordinary soft experimental water was the diluent used in some of the tests. The dilutions were aerated for four days before the introduction of fish, the pH remaining near 7.5. The tests were performed both with and without subsequent continued aeration of the media. All the fish lived for 10 days in these media, which remained slightly alkaline (when aerated continually) or became nearly neutral in reaction (when aeration was discontinued). In other comparable tests performed simultaneously in like manner, the diluent used was very soft water, with total alkalinity and hardness near 5 p.p.m. and 7 p.p.m. as $CaCO_3$, respectively. The pH of the dilutions was about 7.0 to 7.1 during the preliminary aeration for four days, and these media remained nearly neutral or became slightly acid after the introduction of the fish. The test animals died invariably within 24 hr., and mostly within 16 hr.

When the dilutions prepared with the very soft water were not aerated before the toxicity tests, nor during the tests, fish lived in them for at least 48 hr., and nearly all survived for 96 hr. (at pH 6.7 or less). Considerable mortality occurred thereafter, but these recently prepared and unaerated media obviously were not nearly as toxic as similar media which had been aerated for four days.*

Other comparable dilutions were prepared with water having total alkalinity and hardness near 10 p.p.m. and 14 p.p.m. as $CaCO_3$, respectively. Those which were aerated for four days before the toxicity tests (pH about 7.3) and also during the tests proved only slightly toxic. Those which were not aerated were not demonstrably toxic.

* A similar dilute solution which had been stored in stoppered bottles for four days and then tested without any aeration proved somewhat more toxic than the fresh, untreated dilutions, but not nearly as toxic as the aerated ones. All the fish lived for 24 hr., but died within three days. Only one such test was performed.

When the diluent used was pure triple-distilled water, all fish were killed within 24 hr., even without any aeration of the medium (pH about 6.0). Controls were not affected in the distilled water with no salts added.

Other more involved experiments were performed also, but led to no definite conclusions. It is noteworthy that in all the experiments in which the diluents used were very soft or pure distilled waters, the behavior and appearance of the affected or dying fish were suggestive of poisoning with copper, rather than cyanide.

Ferrocyanide Complex (NaCN *with* $FeSO_4$)

Mixtures of NaCN and $FeSO_4$ solutions, in which 482 p.p.m. of cyanide (as CN^-) had been combined with 193 p.p.m. of iron, proved fairly toxic. When they were diluted with the ordinary experimental water, a concentration equivalent to 10 p.p.m. of cyanide proved fatal to all the fish within 48 hr., or much sooner. The variable toxicity of the mixtures was not accurately evaluated. Concentrations equivalent to 1.0 to 4.0 p.p.m. of cyanide were tolerated by all test animals for 48 hr. The $FeSO_4$ solutions (400 p.p.m. as Fe^{++}) had been added gradually to the NaCN solutions as soon as they were prepared, and before any considerable precipitation of iron could occur. The undiluted mixtures contained much brown precipitate, which was removed by filtration before some of the tests, yet they had a pronounced odor of HCN. The final weight ratio of iron to cyanide (as CN^-) was 0.4, or well in excess of the corresponding ratio for the ferrocyanide complex (about 0.36). The precipitation of iron began before the latter ratio had been exceeded.

Pure potassium ferrocyanide (reagent) imparted no odor to solutions of comparable strength, and killed no fish in 48 hr. when added to ordinary experimental water in amount equivalent to 10 p.p.m. of cyanide (as CN^-).

When first NaCN and then $FeSO_4$, in amounts equivalent to 0.33 (or 0.5) p.p.m. CN^- and 0.13 (or 0.2) p.p.m. Fe^{++}, were added to the experimental water, the resulting mixtures proved highly toxic. Even after standing for 3 hr., they killed all test animals within 24 hr. A colloidal precipitate, presumably ferric hydroxide, soon rendered the water brown. The fish died apparently of cyanide poisoning. The weight ratio of iron to cyanide was 0.4, but it is evident that very little if any combination of cyanide and ferrous ions had occurred in the very dilute mixtures. The ferrocyanide complex apparently did not form readily also in similar, very dilute NaCN-$FeSO_4$ mixed solutions prepared with distilled water.

Mixtures of Sodium Cyanide and Paired Heavy Metal Sulfates

A clear mixture of NaCN and $ZnSO_4$ solutions with a weight ratio of zinc to cyanide near 0.6 was prepared, and a small amount of $NiSO_4$ solution was then added, thus combining 553 p.p.m. of cyanide (as CN^-) with 333 p.p.m. of zinc and 72 p.p.m. of nickel. The complete mixture became decidedly turbid. The precipitate formed was similar to those which had been observed when $ZnSO_4$ only was added to a cyanide solution in sufficient quantity, and not like precipitates formed in NaCN-$NiSO_4$ mixed solutions. The mixture proved highly toxic. When diluted with ordinary experimental water to a concentration (0.181 per cent by volume) equivalent to 1.0 p.p.m. of cyanide (as CN^-), 0.6 p.p.m. of zinc, and 0.13 p.p.m. of nickel, it killed all the fish within 16 hr. in two tests.

A similar experiment in which a little $NiSO_4$ was added to a clear mixture of NaCN and $CuSO_4$ solutions, rendering it decidedly turbid, but not reducing its toxicity markedly, already has been reported.

The addition of $NiSO_4$ and of $FeSO_4$

to dilute NaCN-$CuSO_4$ mixed solutions was not found to result in any considerable liberation of copper in toxic form from its cyanide complex. One of the combinations tested was 1.0 p.p.m. of cyanide (as CN^-) with 0.75 p.p.m. of copper (added to the diluent water separately, or as concentrated NaCN-$CuSO_4$ mixed solution) and 0.6 p.p.m. of nickel. Another was 1.0 p.p.m. of cyanide with 0.8 p.p.m. of copper (added to the experimental water as concentrated NaCN-$CuSO_4$ mixed solution) and 0.4 p.p.m. of iron (Fe^{++}). More dilute mixtures also were tested. In each of these tests all the fish survived for 96 hr.

When stock solutions of $ZnSO_4$, $CuSO_4$, and lastly NaCN were added to the ordinary experimental water in amounts equivalent to 1.0 p.p.m. of zinc, 0.025 p.p.m. of copper, and 0.05 p.p.m. of cyanide (as CN^-), the resulting solutions were not demonstrably toxic. Four such tests were performed, and all the fish lived for 96 hr. The same result was obtained even when 1.0 p.p.m. of zinc, 0.25 p.p.m. of copper, and 0.33 p.p.m. of cyanide were combined likewise. On the other hand, in the absence of cyanide, 0.025 p.p.m. of copper combined with 1.0 p.p.m. of zinc invariably killed all the test animals within 14 hr., because of pronounced synergism of these metals (5).* The presence of synergistic zinc evidently did not prevent the inactivation of small amounts of copper by means of cyanide.

Theoretical Discussion

Dissociation constants of the order of 10^{-17}, which have been ascribed to the zinc and cadmium cyanide complexes $Zn(CN)_4^=$ and $Cd(CN)_4^=$ (6), do not signify toxicologically negligible dissociation. On the contrary, in extremely dilute solutions, such as those which proved fatal to 50 per cent of the test animals, virtually complete dissociation of these complex ions is to be expected at any pH. Milne (6) apparently did not compute the degree of dissociation of these complexes at low concentrations, in the manner in which he computed that of the nickelocyanide complex. Such computations reveal that cyanide complexed with some metals in undiluted industrial wastes can be potentially as dangerous to fish as free cyanide. Data presented herein indicate that it may be even more dangerous, because of probable synergism of free cyanide and toxic metallic ions (Zn^{++}, Cd^{++}) liberated when the wastes are diluted. The mode of synergistic interaction of the toxicants is unknown.

The toxicity to fish of extremely dilute cyanide solutions generally is referable chiefly to hydrocyanic acid present in these solutions, and not cyanide ions *per se*. At the average pH of natural fresh waters (between 7.0 and 8.0) most of the so-called free cyanide occurs in the form of molecular HCN (11)(12). Furthermore, there is evidence that the undissociated acid molecule is more injurious to fish than the cyanide ion (11)(13). Unfortunately, the terms "free cyanide" and "cyanide ion" are often used interchangeably (6). The confusing terminology perhaps has led to error. The ions may be physiologically ineffective because of slow penetration through gill membranes, while HCN does not play the role of cyanide ions in ionic equilibria. Cyanide ions resulting from the dissociation of complex ions in a solution of any complex cyanide combine with available hydrogen ions. Their elimination in this manner must result in the liberation of more cyanide from the complex, until equilibrium is reached. The importance, in this con-

* In this connection, it is noteworthy that, under corresponding experimental conditions, 0.1 p.p.m. of copper, but not 0.025 p.p.m. of copper, nor 1.0 p.p.m. of zinc, proved independently fatal to the fish within 24 hr. in a number of tests. Even 0.05 p.p.m. of copper alone and 4.0 p.p.m. of zinc alone have been tolerated by many of the test animals for more than 96 hr.

nection, of variations of pH within the normal pH range for natural waters apparently was overlooked in previously published theoretical work on the toxicity to fish of the nickelocyanide complex, for the dissociation of HCN did not enter into the computations on which conclusions were based.

In the light of above considerations, the observed striking influence of pH variations on the toxicity of the nickelocyanide complex appears to be easily explainable. The familiar ionic equilibrium expression

$$\frac{[H^+][CN^-]}{[HCN]} = K_a$$

(in which K_a is the dissociation constant of hydrocyanic acid, equal to about 7×10^{-10}) shows that if the concentration of molecular HCN is to remain constant, the cyanide ion concentration must be doubled when the hydrogen ion concentration is halved (increasing the pH value by about 0.3 pH unit). From the equation

$$\frac{[Ni^{++}][CN^-]^4}{[Ni(CN)_4^=]} = K_D$$

(in which K_D is the dissociation constant of the nickelocyanide complex) it can be readily deduced also that doubling the cyanide ion concentration while maintaining a constant concentration of nickel ion involves a 16-fold increase of the concentration of nickelocyanide ion ($2^4 = 16$).

The nickel ions present in a solution of sodium nickelocyanide derive from complex ions which dissociate, yielding both cyanide ions and the cyanide present as molecular HCN. However, only a small portion (much less than one-tenth) of the total cyanide so liberated occurs in the ionic form at any pH up to 8.0. Therefore, for present purposes, the concentration of nickel ions may be regarded as being virtually constant so long as the concentration of molecular HCN remains unchanged. It can be concluded that, in order to maintain a given initial concentration of molecular HCN while raising the pH by only 0.3 pH unit, the nickelocyanide ion concentration must be increased nearly 16-fold.

One can reasonably assume that the toxicity of the experimental solutions containing sodium nickelocyanide is referable to, and is determined chiefly by the concentration of, molecular HCN. At pH near and above 7.5, evidently only a minute portion of the total cyanide is free, the remainder existing in the form of relatively harmless complex ions. Thus, it appears that about 16 times as high a concentration of total cyanide combined with nickel should have been required to produce the same toxic effect at pH 7.8 as at pH 7.5. Actually, a 10-fold to 13-fold increase of median tolerance limits was observed in experiments with $NaCN$-$NiSO_4$ mixed solutions when the pH was increased from 7.5 to 7.8. This result seems to agree well enough with the theoretical estimate to justify the conclusion that the suggested explanation of the influence of pH on the toxicity of the mixtures tested is essentially valid.

The foregoing theoretical considerations apply to the nearly straight portions of the curves plotted in Figure 1. Complete and refined theoretical analysis of the relation between pH and the toxicity of mixed solutions of NaCN and $NiSO_4$ has not been attempted, because of evident inadequacy or unreliability of available basic data. The following considerations are believed to be pertinent, however, constituting at least a partial explanation of the sigmoid shape of the empirical curves. The approximations and assumptions whereby the theoretical computation pertaining to the slope of the curves was rendered simple are not valid under all conditions. The toxicity of the most concentrated and alkaline test solutions evidently may not be referable almost entirely to molecular HCN. Some of the ions present in these solutions may have contributed consider-

ably to the toxicity, their relative importance increasing with the concentration and pH of the solutions. With decreasing pH, the proportion of total cyanide occurring as free cyanide increases, until the difference between the concentration of total cyanide and cyanide bound up in complex ions becomes important. The gradual loss of cyanide from very dilute solutions with relatively low pH may have been considerable, augmenting the initial concentration necessary to render the solutions fatal to fish. Free cyanide lost to the atmosphere or otherwise from concentrated alkaline solutions is mostly replaced through dissociation of the nickelocyanide complex, without material reduction of this reservoir of toxicant. Other undetermined factors also may have influenced the shape of the curves plotted in Figure 1.

It has been tentatively assumed that the toxicity of a fairly dilute and not very alkaline sodium nickelocyanide solution to fish is determined predominantly by the concentration of molecular HCN. It seemed reasonable to suppose that the toxicity of the free HCN is not greatly influenced by ionic nickel in the solution. Through comparative examination of test solutions of widely varying pH and total cyanide content, a close relation between the HCN concentration and the toxicity of the solutions has been demonstrated. Proceeding from the foregoing basic assumptions, the author has been unable, however, to reconcile the toxicity data reported herein with a dissociation constant for the $Ni(CN)_4^=$ complex ion of the order of 10^{-22}, the value used by Milne (6) in his calculations. It appeared that if this were the correct value, the experimental solutions should have been much more toxic than they proved to be, and should have had a stronger odor of HCN than they did. Thus, a numerically smaller dissociation constant seemed to be indicated.

Hume and Kolthoff (14) noted that three values for the dissociation constant of the $Ni(CN)_4^=$ ion previously reported in the literature are widely at variance, ranging from 3.6×10^{-13} to 10^{-33}. Their own polarographic results did not permit direct determination of the constant, but they stated that these results indicated "a maximum dissociation constant of about 10^{-24}." They concluded that their polarographic studies indicate the dissociation constant to be of the order of 10^{-22}, the approximate value calculated indirectly from thermal data by Latimer (15), while the two greater published values are quite untenable. However, their results do not exclude the possibility that the true value is considerably less than 10^{-22} and suggest in fact a smaller value. It has been provisionally estimated that a dissociation constant of the order of 10^{-30} would be more nearly in accord with the toxicity test results and the original toxicological assumptions stated at the beginning of the last paragraph. A need for re-evaluation of the constant is indicated, the published values being apparently unreliable.

Penetration of gill membranes by free nickel ions rapid enough for very effective internal detoxification of absorbed HCN through complex formation within the body tissues is deemed improbable for various reasons. Nevertheless, the possibility of some absorption of nickel ion by fish from a sodium nickelocyanide solution and consequent increase of their resistance to HCN in the external medium may not be entirely disregarded. Reliable chemical data are needed for its thorough investigation.

The observed acute lethality of concentrated and very alkaline (not partially neutralized) mixed solutions of NaCN and $NiSO_4$ in distilled or poorly buffered soft water (that is, the most concentrated test solutions listed in Tables IV and V) may be referable mostly to hydroxyl ions. Other ions

present in high concentration, as well as small amounts of free cyanide, also may have contributed to the lethality. This matter was deemed neither practically nor theoretically important enough to be investigated.

Nickel must be capable of replacing zinc and cadmium in their cyanide complexes, forming a more stable complex. The composition of the precipitate observed when zinc was thus presumably liberated from its cyanide complex has not been definitely established. The likelihood of precipitation of the cyanide of the replaced metal, which is set free to combine with remaining complex ions, seems to have been overlooked by Milne (6). In any event, the highly dissociated and very toxic zinc cyanide complex should have been neither eliminated entirely nor rendered harmless when the precipitate in question first appeared. The toxicity test results are in accord with this conclusion.

The chemical reactions which occurred in mixed solutions of NaCN and $CuSO_4$ and the chemical properties and toxicity of the products of these reactions need more thorough investigation. Satisfactory explanation of the curious results of the toxicity tests of these solutions is not possible at the present time. It can be surmised that the toxicity of dilutions prepared with very soft diluent water and containing less than 1 p.p.m. total cyanide (but not that of less dilute solutions prepared with ordinary, moderately soft experimental water) is referable to copper ions. The copper ions presumably derived from relatively harmless and fairly stable complex ions, the dissociation or decomposition of which was promoted by the low pH of the solutions. Prolonged aeration of the solutions must have resulted in accelerated removal of cyanide as volatile HCN and consequent liberation of more copper. The observed increase of the toxicity of continuously aerated solutions cannot be explained otherwise. Free copper is known to be far more toxic in waters lacking in calcium salts and other dissolved minerals than in relatively hard waters.

It has been noted already that the intact ferrocyanide ion has little if any toxicity to fish (3). The toxicity of mixed solutions of NaCN and $FeSO_4$, in which much iron was precipitated, presumably is attributable to residual free cyanide that had not combined promptly with the iron, for which hydroxyl ions compete. The correct explanation of the considerable toxicity of mixed solutions of NaCN and $CuSO_4$ diluted with moderately soft water may be similar, but probably is more complicated, involving the relative instability of various complex ions.

Summary and Conclusions

The toxicity to minnows, *Pimephales promelas*, of mixed solutions of sodium cyanide and sulfates of heavy metals, diluted usually with synthetic soft water, was evaluated. These and other tests were performed in order to learn how dangerous to fish are some of the complex cyanides found in industrial wastes. The potentialities of complex formation as a waste treatment method thus were explored also.

The zinc cyanide and cadmium cyanide complexes, which are believed to be almost completely dissociated in very dilute yet toxic solutions, proved exceedingly toxic. Synergism of the toxic metallic ions and cyanide liberated through dissociation of the complex ions is indicated.

The appearance of precipitates upon the addition of metal salts (including salts of nickel) to waste waters containing cyanides gives no assurance that highly dissociated and very toxic complex cyanides have been eliminated.

Free cyanide combines with nickel ions readily, to form a fairly stable complex, even when their concentrations are very low. Marked reduction of the toxicity of the cyanide, and also of the nickel, occurred as a result of

this combination. The nickelocyanide complex was not appreciably decomposed by direct sunlight.

However, dissociation of the virtually harmless complex nickelocyanide ions is negligible in dilute solutions only when these solutions are decidedly alkaline (pH about 8.0 or higher). Apparently because of increased dissociation at pH 6.5, 1.0 p.p.m. of cyanide (as CN^-) combined with nickel proved more toxic at this low pH than 1,000 p.p.m. at pH 8.0. At the lower pH (pH 6.5), which is well within the pH range of natural, unpolluted waters, the toxicity of cyanide combined with nickel approached that of free cyanide alone.

Hydrocyanic acid is formed by combination of available hydrogen ions with cyanide ions liberated by dissociation of the nickelocyanide complex. The toxicity of dilute solutions of sodium nickelocyanide is believed to be referable chiefly to the free, molecular HCN. The observation that merely doubling the hydrogen ion concentration (for example, reducing the pH from 7.8 to slightly below 7.5) can increase the toxicity of the complex salt more than 10-fold is explainable on the basis of this assumption, with reference to the pertinent ionic equilibrium equations.

The toxicity of moderately concentrated solutions of sodium nickelocyanide, which are quite alkaline, can become much more pronounced when these solutions are diluted, thus reducing the pH.

The concentration of free cyanide only in undiluted cyanide-bearing waste waters obviously is not a reliable measure of the pollutional potency of the wastes. Metal-cyanide complex ions, including the relatively stable nickelocyanide ion, must be regarded as potential sources of toxic hydrocyanic acid, which can kill fish in receiving waters.

Nevertheless, the addition of nickel salts to dilute waste cyanide solutions unquestionably can be an effective method of detoxification of the cyanide for the protection of aquatic life. When there is assurance that the pH of the receiving water will remain sufficiently high until the total cyanide concentration is reduced by dilution to a level which cannot be harmful under any conditions, this waste disposal method certainly is applicable. Waste disposal regulations or standards completely and arbitrarily precluding the application of such disposal methods are not easily justifiable.

The toxicity of waste waters containing free ionic copper can be markedly reduced by complexing the copper with cyanide. Concentrations of copper in the receiving water less than 1 p.p.m., which can be rapidly fatal to fish if the water is soft, apparently can be often rendered harmless in this manner. Extremely toxic mixtures of copper and zinc, which are synergistic metals, likewise can be detoxified by the addition of free cyanide, which combines with the copper.

Concentrations of copper combined with cyanide which are not demonstrably toxic in moderately soft waters can be toxic, however, in extremely soft waters, especially after thorough aeration of the contaminated waters. The toxicity is believed to be due to liberated copper ions.

Although ferrocyanide ions *per se* probably are harmless to fish, the toxicity of very dilute cyanide solutions prepared with soft water was not markedly reduced by the addition of ferrous sulfate. Complex formation evidently was negligible. Cupric ions were more effective than ferrous ions under the same conditions. Both (especially ferrous ions) were more effective when added to relatively concentrated cyanide solutions than in the more dilute solutions.

Acknowledgments

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THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

PROFESSIONAL ASPECTS OF PLANT OPERATION *

BY GEORGE T. LOHMEYER

Superintendent, University of Florida Sewage Treatment Plant, Gainesville, Fla.

In the field of sewage treatment plant operation it is sometimes understandable how occasionally an operator might feel he is a "very small spoke in a very large wheel." It cannot be denied that part of an operator's job can be monotonous and routine with daily pumping operations, daily sampling, routine laboratory analyses, the periodic packing of pumps, the incessant battle against rust and corrosion, the constant necessity for meeting the public with a ready smile, and the endless reading of meters. These list only a fraction of the operator's numerous duties. This routine, coupled with the undeniable fact that the average treatment plant operator is underpaid, presents a situation which makes many people wonder why so many able men remain in the field of water and sewage treatment plant operation.

Example of Professionalism

Several months ago one of the professors from the College of Engineering at the University of Florida was shown through an outstanding, well-operated Florida municipal sewage treatment plant by the plant superintendent. The professor, in describing his visit, made this statement. "It is easy to explain why that particular plant is so well operated. The man who took me through exhibited such inward pride in his job that the plant could have been but one thing, a 'show place in plant operation.' This operator was a professional man, if ever I have met one."

Plant Operation a Profession

What is the professional man, referred to by this professor? The dictionary defines a profession as being a "calling or vocation; especially one that requires learning and mental rather than manual labor." In this sense it follows that the doctor, the lawyer and the engineer are surely professional people. But is it not also true that the nurse is a professional person? The proper performance of her duties requires years of theoretical and practical training even though many of the duties of a nurse consist of manual tasks.

In a like sense water and sewage treatment plant operation, while by necessity requiring more physical exertion than some occupations, is a true profession if each and every operator inwardly feels the importance of the work he is doing. If the operator fails in appreciating fully what he is doing for the good of his fellow citizens he will be nothing more than the mere operator he thinks he is. If he is earnestly proud of his job he will cause

* The *Overflow*, Florida Water and Sewage Works Operators Assn.

people to react to him and his work as the professor did.

Importance of the Plant Operator

How important are the operators of sewage treatment plants? The chief engineer of Florida has this to say. "The importance of the water and sewage plant operator has been recounted many times by listing the benefits of proper plant operation which include such items as a safe water for the home and industry and the protection of our water resources, these to hit only the high points. In Florida, where we enjoy close to a billion dollar annual tourist trade, the operation of water and sewage works assumes even greater importance. Consider for a moment the impact on our tourist trade if just one water-borne outbreak of disease should develop in our state—the answer is obvious." Yes, the answer is obvious and is an answer of even colossal magnitude when it is realized tourism is Florida's largest industry, bar none. Similar instances of the importance of the position of the water and sewage treatment plant operator can be found in every state. This is particularly evident during the summer vacation season when more than 100-million Americans will take to the open roads and visit other towns and states.

Identifying the Professional Operator

Do you know a professionally minded plant operator? You can identify him by the following characteristics:

He fully understands the responsibility placed on his shoulders in maintaining the public health and economy of his community.

He shows he is proud of accepting this responsibility by his every action —on and off the job.

He is constantly working to educate the public on the work his profession is accomplishing.

He works in all activities which aid the progress of his fellow operators through professional societies and through his local municipal government. He also cooperates with all state regulatory agencies.

He can also be identified by observing the plant and plant records he keeps. The record will reveal he is on duty more than the required "40 hours per week."

Last, but not least, he will be a respected man in his community.

Conclusion

Dr. Albert Einstein, the noted mathematician and humanist, said, "a man's value to the community depends primarily on how far his feelings, thoughts and actions are directed toward promoting the good of his fellows." Surely the operators of sewage treatment plants are rendering to a high degree the type of service referred to by Dr. Einstein. It is essential that every operator fully realize this responsibility. When this is done, ours will be a profession in every sense.

SEWAGE PUMPING *

By M. S. Campbell

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Sewage is oftentimes defined as the water-borne waste of the community, which under average conditions contains 99.8 per cent water, with 0.2 per cent mineral and organic solids. The layman might well wonder about the problems of pumping sewage; why should there be any more problems, if sewage con-

* Presented at 1955 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn.; Victoria, B. C.; Oct. 27–29, 1955.

tains only 0.2 of 1 per cent solid matter, than there would be with pumping water? However, for those whose business it is to design, construct and operate sewage pumping stations, the abrasion on pump shafts and bearings and the high maintenance costs due to clogging by sewage solids are way out of proportion to the frequently misinterpreted "0.2 of 1 per cent" as used in the preceding definition of sewage. This is particularly true if in the selection of sewage pumping equipment and the design of stations to house this equipment, the lessons learned from past experience are not used advantageously.

The one common goal always sought after in the design of a sewage pumping station is economical cost of construction, combined with minimum maintenance. These two considerations, however, are not always compatible. Pump selection and pump station design must necessarily be a compromise between low-cost construction and minimum maintenance. If finances are not considered at the time of design, they frequently appear as a factor at the time of receiving bids.

Slightly higher first cost to prevent excessive maintenance costs later can be justified in most cases if the cost of replacing parts and labor, and the benefits of uninterrupted pumping service are all properly evaluated.

Although full advantage should be taken of the knowledge gained by experience in design and operation, the designer and operator cannot afford to neglect the opportunity of taking advantage of new ideas and even adopting or modifying old discarded procedures if benefits can be obtained by varying from what is considered normal practice.

This paper is concerned primarily with the pumping of sewage at small lift stations. It does not attempt a complete coverage of all types of stations. Not only are there a larger number of small stations, but they are beset with more problems.

Lift Station Types

In the selection of the type of sewage lift station, there is frequent opportunity for savings in construction, a part of which could be applied to better selection and arrangement of pumping equipment to keep operation and maintenance costs at a minimum. Depending on the quantity of sewage to be handled, and freedom of the pumping station site from flooding, the lift station design probably will be based on one of three general types:

1. Wet pit installations with vertical pumps.
2. Underground welded steel pump stations.
3. Dry pit installations.

Wet Pit Stations

The wet pit installation employs a vertical type pump with the pump casing suspended directly in the wet well through vertical shafting. Discharge piping and the motor are supported at ground level. This type of design is particularly adapted to the small station and provides the most economical type of over-all construction. The most advantageous use of this type of station in reducing costs, that is not always used to full advantage, is without any construction to house pump motors and controls. The above ground structure can, in many cases be omitted entirely, employing totally enclosed motors and weatherproof controls. Actually in many sections of the United States there is not sufficient icing in the winter to interfere with the float switch operation, which might be the only operating difficulty to be encountered with this type of construction.

Whereas the wet pit installation has its cost advantages for the small station, it does have the disadvantage of having to remove the entire pump assembly (pump, shaft and motor) for inspection or in order to do any maintenance work. This usually involves setting up an "A-frame" or moving a

crane in for the purpose. Also in residential areas, the exposed motors may be an unwelcome reminder to the neighborhood that a sewage pumping station is present.

The wet pit installation employs vertical submerged pumps, because of their economical installation costs. The economy of wet pit construction may be used to advantage even with a horizontal type pump. There is no question that the horizontal unit is easier to maintain and service. The horizontal pump may be successfully utilized by placing it at ground level with the suction in the wet pit, and by providing automatic vacuum-type primers. No concern would be felt about this type of installation if designers were aware that automatic repriming of sewage pumps is possible, rapidly and without any appreciable delay.

Several fish pumping systems employing horizontal 8- and 10-in. nonclog sewage pumps in conjunction with automatic priming systems unload fish from the holds of boats with suction heads as high as 26 ft., under conditions where it is impossible to maintain the inlet suction hose submerged, and where suction is broken and restored rapidly at frequent intervals. Actually the priming requirements on a sewage lift station would not be as severe as in this service; however, advantage has not been taken of this type of design.

Prefabricated Stations

Although there is no question that pump motors and controls are best installed above ground, local conditions sometimes make such installations impractical, or even impossible. Then a solution in the form of a prefabricated, water-tight underground pumping station, often will prove quite satisfactory. Such stations (Figure 1) can be installed anywhere, in parking strips, parkways, or even beneath the streets and at busy intersections. They are dry stations, with tight covers and without structures above ground.

Damage from underground water seepage is eliminated by means of a

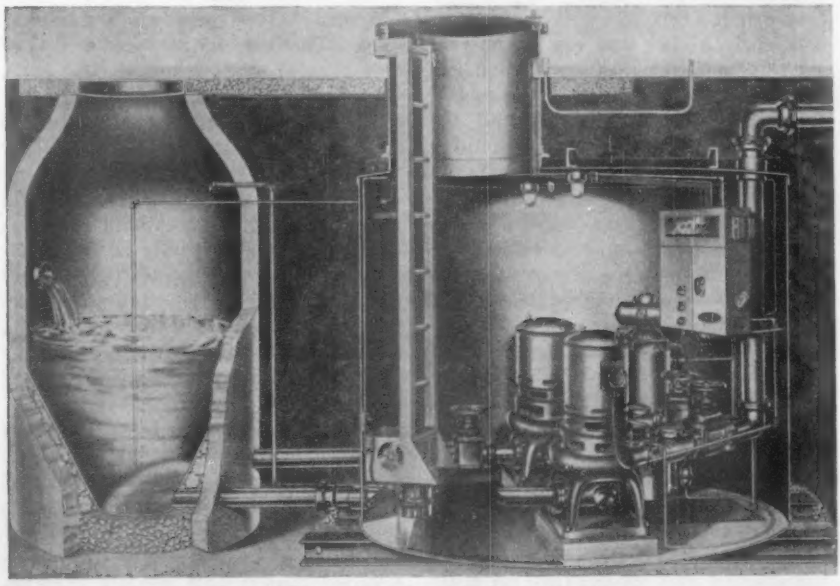

FIGURE 1.—Underground pumping station.

welded steel watertight chamber. This steel shell covers both pump chamber and entrance tube. Pumps and controls are located in the watertight chamber with the chamber being set immediately adjacent to a manhole which serves as the wet well and from which the pumps in the watertight chamber take suction.

Generally, the stations are completely prefabricated, ready for installation. It is only necessary to lower the station in place, make the piping connections, and install the conduit and wiring, and the unit is ready for operation.

This type of underground station is available from a number of pump manufacturers in either standard or flood-proof types. With the flood-proof type, for use where danger of complete submergence makes an ordinary installation impossible, an extra drum is furnished which extends down to a point considerably below the elevation of the electrical equipment and controls. The motors and controls are located in the air-locked space in the upper part of the chamber. Even with a considerable head of water above this chamber and with the cover removed from the manhole, water cannot rise high enough above the bottom of the drum to reach motor windings, electrical controls or connections. Vertical pedestal-mounted pumping units are usually employed in this type of station.

Dry Pit Stations

For the larger sewage lift stations, with flows requiring pumps having 8-

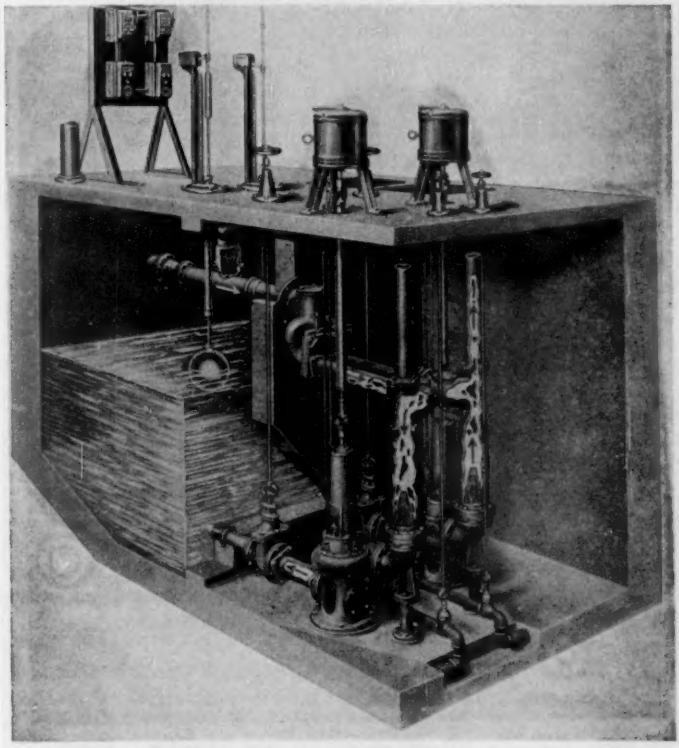

FIGURE 2.—Dry pit pumping station utilizing screening pumps.

in. or larger flanged connections, dry pit construction (Figure 2) is invariably to be recommended. Pumps may be horizontal, vertical with motor pedestal-mounted, or vertical with motor mounted on the operating floor at ground level. The latter utilizes extended shafting between pump and motor. Again the horizontal-type pump would be preferable, except for the large space requirement. The possibility of flooding may limit the selection to vertical units with extended shafting. Any of these pumps and motors may be successfully used in place of the special screening-type pump shown in Figure 2.

Where space is a serious consideration and protection against flooding of the dry pit does not have to be provided, then vertical pedestal-mounted units would be a logical choice. Irrespective of the pumping equipment selected, there should be a complete separation, with watertight construction, between the wet pit and the dry pit. This is necessary to minimize condensation and avoid flooding of the dry pit due to power outage or pump failure.

On all main trunk sewers preceding sewage treatment works, consideration should be given to the installation of grit removal and screening devices. There is justification for installation of these devices on main interceptors immediately preceding treatment, inasmuch as they should be provided at the treatment works in any event, and if they can be located ahead of a main lift station just preceding treatment, so much the better.

The majority of lift stations are not equipped with screening devices of any type. The question of providing screening ahead of lift stations is a paradoxical one, since it can be reasoned that for the small stations, where screening is most needed, their installation is too costly, and in the large stations, where screens can be afforded, their need is not so well defined, since the larger units will pass larger solids with fewer stoppages.

Pump Selection

The selection of pumping equipment after the head and capacity have been determined is a relatively simple matter when pumping water. Either the capacity is small and an end-suction pump may be used, or if the capacity requirement is large a double suction pump with split case can be used. It then becomes just a matter of selecting the proper pump size to fit the head and capacity requirements. Not so in the selection of a sewage pump. Location, total head, capacity, flow variations, grit quantities, and the relationship of friction head to total dynamic head, all must receive consideration before a proper selection can be made. Selection may be made from a relatively wide range of pumps: the "non-clog" centrifugal in either horizontal or vertical types; the "bladeless" centrifugal in either horizontal or vertical types; the pneumatic ejector of the Shone type; the duplex units with built-in screens, such as the "Flush-Kleen"; and the newer "torque-flow solids" type. Each type has definite individual characteristics and applications, a knowledge of which is essential in proper selection for any specific job.

Non-Clog Pumps

The so-called "non-clog" centrifugal pump (Figure 3) is not always non-clogging. Ever since the term "non-clog" was first coined by the sewage pump manufacturers, they have been working diligently to develop sewage pumping units which would be non-clogging, particularly with small flows.

Impellers

The conventional "non-clog" centrifugal sewage pump impeller has two vanes enclosed by two shrouds, one on each side of the vanes. The sewage enters the "eye" in the center of the impeller, gaining its velocity of discharge through the centrifugal action of the impeller. Sewage is thrown outward through the ports located

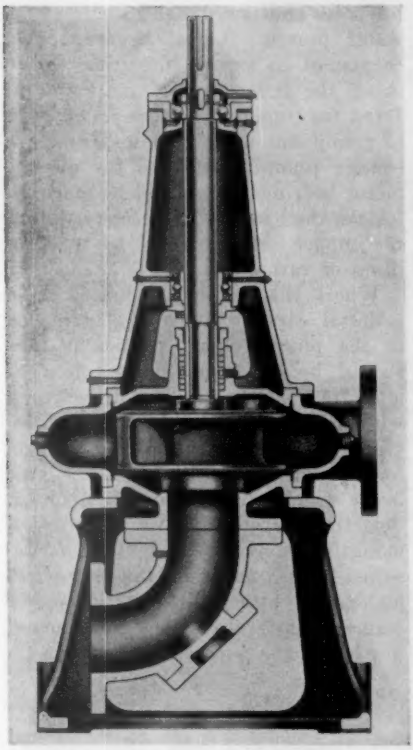

FIGURE 3.—Non-clog centrifugal sewage pump.

within the impeller. These ports are responsible for the clogging of this type pump if they are not large enough and properly rounded and smoothed to pass the size of solids anticipated.

It is interesting to note the development of the "non-clog" type impeller. Early impeller designs were of the open type, that is, with no sidewalls, or shrouds attached, and they usually approximated paddle wheels. As experience was gained, semi-enclosed impellers, with a shroud on the packing gland side of the impeller which extended from the impeller hub to the outer circumference, soon followed. Still more experience resulted in the fully-enclosed impeller, that is, with shrouds on both sides of the vanes forming enclosed ports between the impeller eye and the circumference of the impeller.

Advantages of the enclosed impeller are: (a) close clearances are not required for efficient performance; (b) a higher efficiency is obtained since there is no fluid slippage past the vanes; (c) wear on the impeller is slower, since the impeller vanes do not have to maintain rubbing clearances with the top and bottom, or side plates; and (d) the enclosed impeller provides maximum freedom from clogging as the enclosing shrouds allow maximum freedom for rounded blade edges and waterways.

Repelling vanes have been placed on the back of the shroud closest to the casing end through which the impeller shaft passes. These vanes have the shape of impeller vanes, but are smaller and usually four in number. Repelling vanes accomplish the following principal functions: (a) provide a slight vacuum which tends to draw lubricant, or water-seal water through the bearing or packing gland in the direction of the discharge; (b) eliminate the fluid pressure against the lower sleeve bearings in submerged pumps of the wet pit type, or the packing gland on dry pit pumps; (c) prevent grit from getting behind the impeller; and (d) eliminate the possibility of stringy material winding around the shaft or impeller hub. The repelling vanes assure a constant flow of lubricant or seal water through the bearing surface, passing out through the impeller discharge, thereby preventing abrasive materials from working into the bearing.

Because of the design of non-clog type impellers, particular attention must be devoted to the use of this impeller on high heads. When the discharge head increases it is necessary to increase the number of vanes or ports from two to three, or possibly four, in order to meet the head requirements. Obviously when this is done the water passages through the ports are decreased to make room for the

additional vanes. For example, an impeller used on a low head application can have a 4-in. diameter impeller eye opening with 4-in. by 4-in. port openings in the two vanes. The addition of more ports to take care of a higher head condition may reduce the passages between the shrouds and impeller vanes to 2 in. by 4 in. Thus, while the impeller eye opening may remain the same, the ability of the ports to pass solids is reduced by 50 per cent.

The alternate choice, although undesirable, is to increase the speed of the impeller. In high head applications, consideration should be given to the use of two pumps in series, thereby maintaining two port impellers in both pumps with 4-in. openings without an increase in speed.

Another critical condition encountered in the selection of a non-clog type pump for small capacities is the fact that the pump is operating very close to the shut-off head. Designers must use extreme caution in pump selection for this type service since a difference of 1 or 2 ft. in total dynamic head can result in a variation in pump capacity of as much as 20 per cent, since sewage pump curves are quite flat, as compared to a similar size pump for water. For example, with too much tension on a spring-loaded check valve, the pump would not perform as anticipated.

Mountings

Most pump manufacturers have available what is known as "close-coupled" pumps. The close-coupled pump has the impeller mounted directly on the end of an extended motor shaft with no bearings in the pump housing. Accordingly, all of the load is carried by the motor bearings. In the direct-connected type pump flexible coupling is employed between the motor shaft and pump shaft, and there are bearings in the pump housing.

The close-coupled pump was developed first for water recirculation purposes and low lift end suction type water pumps. Later, in attempting economies in sewage pumping equipment, the close-coupled pump was offered for pumping sewage. This type of pump has a very limited place in sewage pumping because the electric motor bearings should not be expected to take the load of the motor as well as the impact loading caused by the handling of raw sewage.

Where the motor is mounted on a pedestal directly above and attached to the pump casing, particular care should be given in the selection of mounting. There is nothing wrong with the use of a flexible coupling provided the pedestal supporting the motor is sufficiently strong to carry the loads which will be placed upon it. Sometimes where light weight pedestal mountings were accepted, vibration resulted to such an extent that guy wires had to be attached from the motor frame to the walls of the pumphouse, to prevent the pump from walking.

Efficiency

High efficiencies in a well designed sewage pump should neither be asked for nor expected. In order to pass solids freely, a sewage pump must have large open passageways, eliminating the possibility of high efficiencies. The best efficiency range for a non-clog type sewage pump is from 60 to 65 per cent. If the efficiency is above these limits, a second look should be taken. There may be a good reason in some cases for higher efficiency, but generally the claim of a high efficiency solids handling pump should be considered with suspicion.

Speed

The lower the impeller speed the longer the life of the pump and the less maintenance required. Pump speeds of 1,150 r.p.m. or less are to be desired. In general, the lowest speed capable of meeting the head requirements should always be selected.

Size

It is now generally recognized that a non-clog centrifugal pump with inlet and outlet openings of less than 4-in. should not be used for pumping sewage. It is also recognized that a sewage pump should have openings large enough to pass a minimum-size solid of 2½ in., and preferably 3 in. These limitations create the major problem in handling sewage solids in small flows. Pumps 4-in. in size have a minimum capacity which exceeds the requirements of most small lift stations. Many centrifugal pump manufacturers cannot supply a sewage pump of less than 150 to 200 g.p.m., while about the smallest capacity available in any 4-in. pump is 75 g.p.m.

Where the available capacity of conventional non-clog centrifugal sewage pumps is too small to assure reliable service, there are four special types of pumps from which selection may be made.

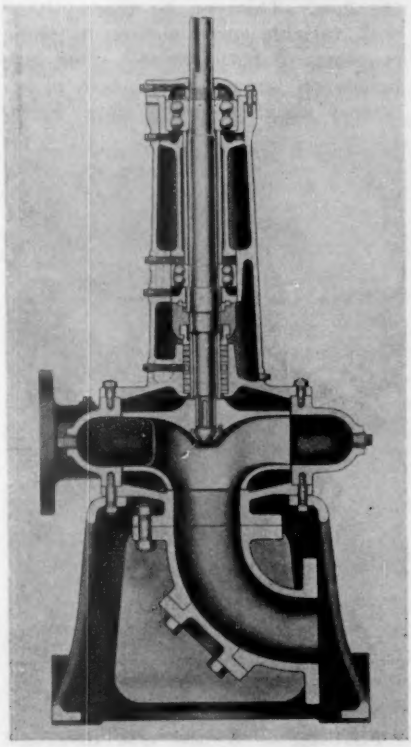

FIGURE 4.—Centrifugal sewage pump with a "bladeless" impeller.

Bladeless Impeller Pumps

The "bladeless" impeller pump (Figure 4) is a modification of the two-port, non-clog centrifugal pump, in that it has a single blade providing one port through which the flow passes from the impeller eye out of the impeller. Just as in the case of increasing the number of ports to gain head results in loss of ability to pass solids, here reducing the number of ports increases the size of opening within the impeller. This type of pump will deliver approximately one-half of the flow of the same pump of a non-clog type, and requires a little more than one-half the horsepower. On the other hand, the "bladeless" pump is several times harder to clog than its conventional counterpart.

Screening Sewage Ejectors

The screening sewage ejector (Figure 2) is fundamentally two non-clog centrifugal pumps operating in parallel, with screens built in so that only screened sewage enters the pump casing, thereby eliminating clogging. One pump operates while the other passes screened sewage into the wet well, then on the next cycle of operation the function of each is reversed. Consequently, for a lift station with a rated capacity of 100 g.p.m., each of the two units must have a capacity of 100 g.p.m. These pumps are particularly adapted for low flows and high heads.

Pneumatic Ejectors

Pneumatic ejectors (Figure 5) of the Shone type are one of the oldest and most dependable types of sewage pumping equipment. Their best application, however, is limited to low flows and low heads. In capacities exceeding 400 g.p.m. these units are not in competition with non-clog pumps, and they should be limited to heads

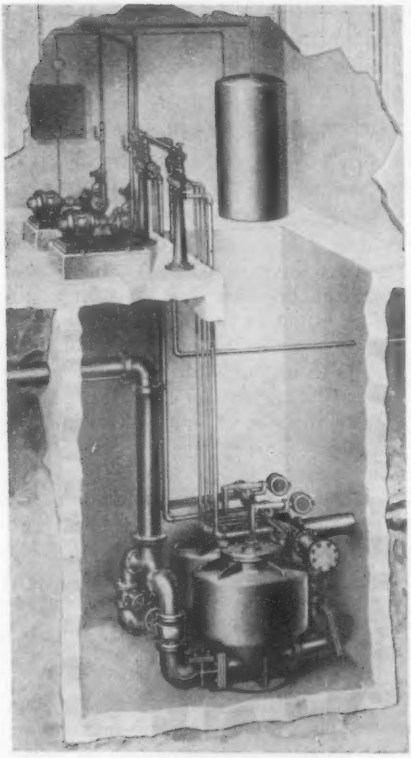

FIGURE 5.—Pneumatic sewage ejector.

of 50 ft. or less, due to the efficiency lost in compressing air at higher heads. Pneumatic ejectors have the advantage of handling any size solid that will pass through the inlet and outlet piping and they are able to operate under totally submerged conditions. Their use should be considered in any installation where considerable amounts of grit and sand must be handled, for example, at a seaside resort community since sand is readily ejected without coming in contact with any moving part.

Torque-Flow Solids Pump

A new development in the sewage pumping field is the "torque-flow solids" pump (Figure 6), which is a centrifugal pump with no impeller eye opening. This development incorporates the application of the torque conversion principle, in which the discharge velocity is created by the rotating fluid, induced by the impeller. The fluid is not required to pass through any impeller openings. This unit is available in capacities up to 2,000 g.p.m. and for a wide range of heads. It has not been perfected for capacities less than 200 g.p.m. The horsepower requirement is approximately 25 per cent greater than that required for the conventional non-clog centrifugal pump. Applications of this pump for both sewage and sludge pumping have shown no problems from clogging.

Number of Pumps

The ideal selection of pumps for any pump station would be one in which the discharge would vary directly with the flow. This can be accomplished with variable speed motors, magnetic couplings or with variable pitch propellers on large pumps. Loss of efficiency under a varying speed condi-

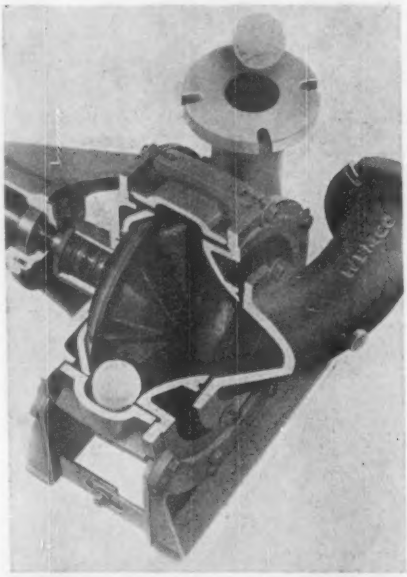

FIGURE 6.—A new type centrifugal sewage pump which operates on the "torque-flow solids" principle.

tion and maintenance problems of variable speed control equipment have usually rendered these methods unsatisfactory.

The most practical approach is by step operation of the pumps to approximate the flow curve. Selection on this basis may indicate three, four, or even five pumps. A basic selection of three pumps assumes there are no extreme variations due to storm flows. With three pumps, one unit would be equal to the peak flow anticipated and the remaining two would be of equal capacity, but with their combined capacity equal to one-half of the peak flow. For example, with a peak flow of 500 g.p.m., one 500 and two 125 g.p.m. pumps would be selected. Under this method, peak flows can be handled with the large unit alone. One of the small pumps running perhaps 90 per cent of the time or the two smaller units dividing the flow alternately, could handle the low or normal flows. The large unit possibly would operate only 10 per cent of the time. Repairs and maintenance are confined chiefly to the smaller units.

In the selection of the number of pumps and their capacity, the relationship between friction head and total dynamic head is exceedingly important. If the friction head is of any consequence, for example, due to a long force main, then the actual output of any pump when more than one pump is operating may not even resemble the condition for which the pump was selected. In the previously cited example of one 500 and two 125 g.p.m. pumps, if the friction head is large and the 500 g.p.m. unit was operating in conjunction with the two 125 g.p.m. units, then the pump rated at 500 g.p.m. may be delivering only 300 g.p.m. In fact, it could be that one of the 125 g.p.m. pumps would deliver its rated capacity when operating alone, but that with both the 125 g.p.m. pumps operating, a combined flow of only 150 g.p.m. would be obtained.

The reason for this is the flat characteristic curve of any pump designed to pass large sewage solids and the wide variation in capacity with small change in head. It is important, therefore, that a system curve be developed for any lift station in order to determine the output of all combinations of pumps under all head conditions.

Operation and Maintenance

While the subject of operation and maintenance of pumps alone merits an entire separate discussion, there are some comments which cannot be omitted from any pump discussion in the interests of better operation and maintenance.

In the first place, the performance curve of every pump in the system should be obtained from the pump manufacturers. The actual output of each pump and operating head should be checked against the curve. Periodic pump checks against the curves may disclose a number of operating deficiencies. Worn impellers, stuck check valves, too much tension on spring-loaded check valves, or a drop in output due to speed reduction as a result of low voltage may be detected in this manner.

Another important check that can be made, even on old installations, but more particularly on a new installation, is to see that the correct heaters are installed in magnetic starters for overload protection. A heater that has too high an amperage rating may result in a burned-out motor.

Any bearing that has been submerged in water should be immediately replaced. It will go out sooner or later and perhaps take a good shaft with it at an inconvenient time.

Improper lubrication, either too much or too little, is a frequent cause of bearing failure. Remember, that if a sleeve bearing is running too hot—it does not have enough grease. If a ball bearing is running too hot—it has too much grease. A sleeve bearing may take as much as an ounce of grease

per day, whereas a ball bearing possibly should not have over one ounce of grease in six months.

Summary and Conclusion

Sewage pump selection must be made entirely on the basis of the job to be handled. If the flow is large enough to assure large passages in the pump with slow speed, then a so-called "non-clog" centrifugal pump should be selected. High pump efficiency should not be expected with openings large enough to pass sewage solids nor at slow speeds. Small sewage flows should be handled with one of the special pumps designed particularly to handle small capacities.

INTERESTING EXTRACTS FROM OPERATION REPORTS

"Life is not built as a solid mass; it is built of individual days cemented by motives, hates and loves.—*W. W. W. Argow.*

Attention operators! It will be appreciated if copies of the annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Report of the Minneapolis-Saint Paul (Minn.) Sanitary District for the Years 1953 and 1954 *

By Kerwin L. Mick, *Chief Engineer and Superintendent*

General

Operations of the Sanitary District treatment facilities continued normal during this two-year period following the spring flood of 1952. Report of the Corps of Engineers disclosed that the estimated cost of permanent flood protective works could not be justified.

Expansion needs of the treatment facilities and the sewer system are being given increased study in preparation for future requirements. It has been estimated that the sewage flow will increase 20 m.g.d. per year.

The names of seven employees were added (1954) to the roster of employees having 20 years of service, bringing the total to nine. However, death claimed two employees in 1953, one being the first employee to have 20 years of service.

Operation

The total flow established a record in 1953. This represented a continued increase, first apparent in 1951.

The values in Table I are indicative of the increased load. Per capita values are based on the estimated tributary population.

Assuming 0.18 lb. of 5-day B.O.D. per capita per day for domestic sewage only, the population equivalent of the sewage and wastes received at the plant during 1953 was 1,240,000 or 36 per cent greater than the estimated population of 914,000. For 1954 the population equivalent was 1,360,000 or 46 per cent greater than the estimated population of 932,000. Industrial wastes accounted for the major part of this difference, and according to these figures would amount to 26 and 31 per cent, respectively, of the pollution load on the plant.

The raw sewage strength showed an increase in 1953 and 1954 when com-

* For last previous extract see This Journal, **26**, 7, 912 (July, 1954).

TABLE I.—Comparison of Load, 1952–54

Item	1952	1953	1954
Population, tributary (est.)	907,000	914,000	932,000
Sewage flow (m.g.d.)	135.2	142.6	138.6
Sewage flow (g.p.c.d.)	149	156	149
Susp. solids, infl. (lb./cap./day)	0.32	0.33	0.34
B.O.D., infl. (lb./cap./day)	0.21	0.24	0.26

pared with 1952. Total solids averaged 796 and 820 p.p.m., respectively, compared with 765 p.p.m. in 1952. Suspended solids averaged 265 and 276 p.p.m. for 1953 and 1954, respectively, compared with 251 p.p.m. in 1952. The B.O.D. showed a corresponding increase from 172 p.p.m. in 1952 to 188 p.p.m. in 1953 and 212 p.p.m. in 1954.

The extreme ranges of sewage strength are also of interest, in contrast with the average values. The B.O.D. is usually at a minimum on a Sunday following or during a heavy run-off from rain or snow, at which time it is approximately 60 p.p.m. The maximum B.O.D. for the years 1953 and 1954 occurred on the Wednesday before Christmas. In terms of suspended solids the raw sewage strength is at a minimum on Sunday. Maximum concentration of solids occurs when unusual quantities of grit are flushed through the interceptor sewer by either an extremely heavy rain or a thaw.

Sludge Conditioning and Filtration

Raw sludge is pumped from the settling tanks at the greatest practicable concentration, averaging 7.25 and 6.65 per cent, respectively, for the two years, 1953 and 1954. The pH averaged 6.1. The character of the sludge may vary considerably from day to day as the result of storms, industrial wastes and changes in the domestic sewage.

The average chemical dosages required to condition the sludge for filtration, based on the dry sludge solids, were:

Chemical	Dosage (%) 1953	1954
Lime	2.94	3.23
Ferric sulfate	1.14*	1.17*

* As equivalent ferric chloride.

These dosages were about the same as required during the latter part of 1952 when chemical requirements increased materially.

Continued difficulty was experienced with blinding of the filter cloths, necessitating more frequent washing and acid baths. This is believed to be principally the result of an increasing content of oils, fats and greases (and perhaps detergents) in the sludge and is tied in with the difficulty experienced in pumping sludge through the pipe lines. Deposits on the pipe walls required frequent scrapings at intervals ranging from three weeks to five months. In 1954, the 6-in. sludge suction lines required cleaning for the first time.

A sloping baffle was installed during 1953 in the sludge conditioning tank in order to intermix more completely the sludge mass and chemicals prior to filtration. Subsequent pH tests indicated a more uniformly conditioned sludge. It is hoped that this change will result in an improvement in filter cloth life and a decrease in chemical dosages.

In November, 1954, 32-mesh Saran filter cloths were installed on the 8 vacuum filters for experimental use under actual plant operating conditions. Results of the tests indicated the following:

1. Production per filter averaged about 10 per cent more dry tons for those covered with Saran cloths compared with the regular cotton cloth.

2. Saran filter cloths required fewer washing periods than the cotton cloths.

3. Saran cloth was not nearly as subject to conditioned sludge variations as the cotton cloths.

4. Saran cloth produced a filter cake which was uniform over the entire face

of the filter compared with spotty cake production of the cotton cloth, due to the latter becoming easily "blinded" from embedded sludge particles and excess chemicals.

5. Filter speeds could be appreciably increased with the Saran cloth filters, with no loss in filter cake production, while this did not hold true for the cotton cloth filter under the same operating conditions.

With all of the conditioned sludge being filtered through the Saran cloths for the last 58 days of 1954, the following operating results were noted:

1. The iron coagulant dosage requirement was drastically reduced from an average of 2.25 per cent ferric sulfate as Ferri-Floc, equivalent to 1.30 per cent $FeCl_3$, based on the dry sludge solids for the first 10 months of 1954 using cotton cloths, to an average of 0.88 per cent ferric sulfate as Ferri-Floc, equivalent to 0.51 per cent $FeCl_3$, for the last two months of the year with Saran cloths.

2. The lime requirements also showed a slight decrease from a 10-month average of 3.28 per cent CaO to the average of the last two months of 2.97 per cent CaO.

3. Where the time interval between washing periods with cotton cloths was 1 hr., it was found that this could be increased to a 2-hr. interval with the Saran cloths. This effected labor, power and water economies.

Other advantageous factors developed through the use of these Saran cloths. One of the most significant developments appears to be the increased life of these cloths. Where formerly the cotton cloths gave a service life of only 400 to 500 hr., with an acid bath or two between 150 and 300 hr. to remove cloth "blinding," the sludge was still being filtered through the 8 original Saran cloths at the end of 1954. At that time the average life of the six cloths installed early in November was 1,252 operating hours, ranging from 1,217 to 1,317 hr. The two cloths installed in December had operated for 434 and 571 hr. Acid baths for filter cloth "blinding" were not required at any time during the two months of operation with the Saran cloths.

A definite change in the sludge filtrate solids content was noted because of the Saran cloth operations. Although the average filtrate total solids content for November and December increased to only 4,300 p.p.m., compared to an average of 3,700 p.p.m. for the first 10 months of 1954, the suspended solids content increased to an average of 1,600 p.p.m. from an average of 160 p.p.m. for the same periods. However, the per cent of volatile matter in the filtrate suspended solids for these periods showed practically no change, being 65.9 per cent and 65 per cent, respectively. Inasmuch as the thickened sludge volatile solids content showed an increase from an average of 71.9 per cent for the first 10 months to an average of 76.5 per cent for the last two months, it can be assumed that the increase in the filtrate suspended solids was mostly of an inorganic nature.

However, the Saran cloths produce a wetter filter cake, averaging 71.6 per cent moisture for November and December, compared with 69.4 per cent for the first 10 months of the year with cotton cloths. This wetter filter cake requires some adjustments in the operation of the incinerators but no serious difficulties were experienced.

The use of carbide lime slurry instead of pebble quicklime was begun in April, 1954. The slurry as delivered in a tank truck contained 25 to 30 per cent solids averaging 68 to 72 per cent CaO. Storage for 25,000 gal. was provided. Usage was 3,000 to 5,000 gal. daily, fed through a diaphragm slurry pump, adjustable for different rates of feed. In the 8 months of carbide lime slurry use in 1954, 250 truck loads were received

containing 901 tons of CaO at an average delivered price of $12 per ton of CaO, compared with $17.87 for pebble quicklime per ton of available CaO content, a saving of approximately one-third. At this rate of saving, the slurry installation should pay for itself in less than 1½ years. The carbide lime slurry appeared to be equally effective with quicklime and was easier to handle and feed.

Daily filter cake production averaged 358 tons (114 tons dry solids) in 1953. Daily production increased in 1954 to 387 tons (117 tons dry solids). The total quantity of wet filter cake produced was 123,566 and 141,330 tons, respectively, in 1953 and 1954. The original design anticipated an average of 76 tons of dry solids would be removed daily.

Incineration of filter cake totaled 123,384 tons (wet) during 1953 and 138,528 tons (wet) during 1954. In spite of the record high tonnage incinerated, improved operation of the incinerators continued. An operating record was established by incinerator No. 4, which was in operation continuously without shutdown for 604 days from May 6, 1953 through December 31, 1954, and was expected to continue in operation well into 1955.

Maintenance and Equipment Changes

New chains, guide strips, sprockets and rake bushings were installed on the bar screens as required. Grit washers Nos. 1, 4, 5 and 6 were overhauled in 1953 and units Nos. 2, 3 and 8 were overhauled the following year.

Improved safety features were incorporated into the plant facilities. Grating was installed near the top of the grit washers for easier inspection during operation. Guard railing was placed around the overhead counterweights that balance the float gates in the influent channels. Provision was made for the use of portable railing when the inspection doors of the grit chambers are opened. Safety treads were installed on some terrazo steps leading to the locker rooms.

An electric vibrator was installed on the bin in which Ferri-Floc is stored, to facilitate transfer.

Occasional breakage of the redwood sludge scraper flights continues, primarily at bolt holes. The main collector chain in clarifier tank No. 3 was turned in 1950 and new attachment links installed. The chain in the flocculators was turned in 1954, completing the turning of all the collector chains. All tanks were dewatered and inspected. Repairs to rails, drive chains and shoes were made where necessary. The cross-collector chain in tank No. 1 was replaced in 1953 after 15 years of service.

Several changes in piping were made to facilitate operation and cleaning. The two original 6-in. sludge lines from the sludge concentration

TABLE II.—Summary of Operating and Maintenance Costs for 1953 and 1954

Item	1953	1954
Operation		
Salaries	$403,098.76	$432,673.77
Materials and supplies	78,782.26	82,564.15
Power	32,897.89	34,432.76
Miscellaneous	50,360.59	55,199.82
Maintenance		
Salaries	75,846.46	74,229.37
Materials and supplies	32,216.50	40,381.44
Subtotal	108,062.96	114,610.81
Total	673,202.46	719,481.31
Per capita*	0.74	0.77
Per m.g.d.	13.50	14.20

* Based on estimated tributary population.

TABLE III.—Summary of Operating Data, Minneapolis-Saint Paul Sanitary District, for the Years 1953 and 1954

Item	Average 1953	1954
Rainfall (in.)	28.03	23.68
Population, connected (est.)	914,000	932,000
Equivalent population	1,240,000	1,360,000
Sewage flow (m.g.d.)	142.60	138.59
Screenings (cu. ft./m.g.)	0.8	1.1
Grit removal:		
Amount (cu. ft./m.g.)	4.9	5.7
Volatile solids (%)	7.7	10.2
Dissolved oxygen (p.p.m.):		
Raw sewage	1.15	0.65
Settled effluent	4.45	3.75
Settling tank detention (hr.)	1.4	1.4
B.O.D., 5-day:		
Raw sewage (p.p.m.)	188	212
Settled effluent (p.p.m.)	118	133
Removal (%)	37.2	37.5
Suspended solids:		
Raw sewage (p.p.m.)	265	276
Settled effluent (p.p.m.)	83	81
Removal (%)	68.8	70.8
Settleable solids:		
Raw sewage (ml./l.)	6.7	7.4
Settled effluent (ml./l.)	0.26	0.26
Removal (%)	96.3	96.6
Volatile solids (%):		
Suspended, raw sewage	73.0	78.2
Susp., settled effl.	73.8	78.5
Total, raw sewage	45.2	47.6
Total, settled effl.	36.8	38.3
Raw sludge:		
pH	6.0	6.1
Total solids (%)	7.25	6.65
Volatile solids (%)	70.3	73.4
Thickened sludge:		
pH	5.9	5.8
Total alkalinity (p.p.m.)	945	1,000
Total solids (%)	8.18	7.7
Volatile solids (%)	69.6	72.6
Filter cake:		
Total solids (%)	31.9	30.2
Volatile solids (%)	66.7	69.5
Produced (wet tons/day)	358.1	387.2
Produced (dry tons/day)	114.4	116.9
Conditioning chemicals:		
CaO (lb./100 lb. dry sol.)	2.94	3.23
$FeCl_3$* (lb./100 lb. dry sol.)	1.14	1.17
Sludge filter rate:		
Wet cake (lb./sq. ft./hr.)	10.4	11.1
Wet cake (lb./sq. ft. filter area used)	0.99	1.14
Incineration:		
Combustibles (tons/day)	76.2	79.8
Moisture evaporated per ton of combustibles (tons)	3.3	3.4
Ash produced (dry tons/day)	38.0	35.0
Power (kw.-hr./ton dry sol.)	8.5	8.7
Fuel oil (gal./ton dry sol.)	0.38	0.36
Filter cake disposal, total:		
For fertilizer, total (dry tons)	56.5	815.7
Incinerated (dry tons/day)	114.2	114.7

* Ferric sulfate used, but calculated to equivalent ferric chloride.

tanks to the elevators were replaced with 8-in. pipe and cross-connected for greater flexibility and capacity.

New steel wire screens were installed on filters Nos. 2, 3, 5, 7 and 8 in 1953, and on filters Nos. 1, 3, 4, 5, 7 and 8 in 1954. The average life of the screens is approximately 16 months due to loss of metal during acid baths. Plastic coating is being tried to lengthen the life of the screens. The wood strips on filter No. 6 were renailed with stainless steel nails. New wash water troughs were installed in filters Nos. 3, 4 and 6. Repairs and replacements were made to bucket elevators, various belt conveyers and other sludge handling units or appurtenances.

During 1954 the most extensive repairs since the plant was placed in operation in 1938 were started to incinerators Nos. 1, 2 and 3. Several of the hearths were completely rebuilt from the steel shell or the wall brick. Approximately 70 per cent of this work had been completed by the end of the year. During the two-year period reported herein, 11 rabble arms and 105 teeth were replaced with either new or repaired material.

High operating temperature, moisture and acid have caused excessive corrosion of the dust precipitator. Considerable maintenance was necessary, but the need for complete replacement within the next few years is apparent.

Several pumps of all types were completely overhauled. The planned preventive maintenance of equipment, especially motors, motor controls and relays has resulted in few emergency breakdowns.

Laboratory

Routine plant sample analyses occupied approximately 40 per cent of the laboratory staff's time; routine river sample analyses, 14 per cent; collection of river samples, 10 per cent; records and analysis of data, 9 per cent; special analyses, investigations and test of materials, 18 per cent; and maintenance of equipment, supervision and miscellaneous work, 9 per cent.

A new 10-place B.O.D. bottle washer was built for the laboratory.

Costs

The operating and maintenance costs for 1953 and 1954 are summarized in Table II.

Salaries account for approximately 60 per cent of the costs. Rising costs of labor, supplies and utilities are reflected in the increased cost of operation.

Table III is a summary of the plant operating data for the years 1953 and 1954.

CLOTHING FOR OPERATING PERSONNEL

Beautiful landscaping, shiny, painted equipment and well-kept buildings present an attractive picture. Closer inspection, however, may reveal personnel who are sloppily dressed. If shirts are dirt and sweat stained, or trousers are grease covered, the personal appearance of the employees cannot be good. Of course it is usually the exception rather than the rule to find untidy employees at an otherwise immaculate sewage treatment plant. Unfortunately, many well-operated plants do neglect the appearance of the operating personnel. As a result the good public relations of the plant are jeopardized.

Clean, attractive and serviceable clothing for operating personnel will contribute much to operator morale and plant public relations. There are several approaches to the problem of clothing.

1. Employees can be instructed to wear clean clothing subject to the in-

spection of the superintendent. This places a considerable burden on the employee to furnish sufficient changes of clothing and to keep them clean. A conglomeration of outfits may be worn, varying from coveralls to shirts and trousers. Furthermore, it places the superintendent in the position of holding a formal or informal dress review each day.

2. Uniforms can be furnished to each employee by the treatment plant. This provides for standardization of dress and makes for an attractive, neat impression on the visitor. Several large treatment facilities supply uniforms for their personnel and find the results to be most gratifying.

Selection of Clothing

Whether the uniform is furnished by the employee or the treatment plant it should meet certain standards of uniformity and construction. It must be practical, fit the working conditions of the plant, be distinctive and popular with the men who wear it.

Material

Cotton is the best material for uniforms. It stands up better and can be laundered cheaply and easily. A cotton uniform will wear well for a long time and looks good for the length of its life.

Colored uniforms should be tested for color fastness. A badly faded uniform has a depressing effect on employees and visitors.

Closures

Buttons are generally superior to mechanical closures in work garments. They are cheaper and last longer. Replacement of buttons is easy and inexpensive, but replacement of mechanical closures like zippers is more difficult. Zippers may jam, causing considerable trouble and embarrassment. Metal grippers sometime lose their grip, although they are to be preferred to zippers.

Construction

Uniforms should be of simple sturdy construction with full seams, well sewn. There should be no "fruit salad" trim on a uniform as such trappings do not launder well and soon look worn and unattractive. Pleats are inappropriate.

For safety's sake as well as appearance there should be no loose or dangling piece of clothing to get caught in equipment. Dangling cuffs catch on projections and cause bad falls. Long, loose sleeves and neckties rank high on the list of hazards.

Cleaning

Dirt is an offender to a good appearance. In addition to detracting from personal appearance, dirty clothing may also create a health and accident hazard. Contact with dirty clothing may cause skin irritation and dermatitis. Infectious bacteria can hitchhike right along to be on hand to complicate cuts, scratches and other minor injuries.

Plant Laundry

Adequate clothes washing facilities can frequently be supplied at moderate cost for the use of plant personnel. An automatic washer and drier located in or adjacent to the locker room will provide a convenient method to keep clothing clean.

These facilities are suitable whether the employee or the treatment plant furnishes the clothing. Hot water is readily available and detergents can be furnished by the plant as an item under cleaning supplies.

One enterprising superintendent purchased a good used washer and drier at a low price. The plant mechanic and electrician placed the equipment in first-class operating condition and maintained it in good working order.

Frequently a local appliance dealer is glad to aid the program by furnishing laundry equipment at a moderate cost. The advertising value to the dealer can be mentioned in negotiating for the equipment.

Commercial Laundry

Commercial laundry facilities are frequently the best solution to the laundry problem, particularly when there are many uniformed employees and several points of operation. Pick-up and delivery service is on a dependable schedule and each group of employees knows when to expect soiled clothing to be picked up.

Commercial laundering provides not only a clean uniform, but a pressed uniform ready for wear. Its use eliminates problems connected with a plant laundry, such as the use of the laundry equipment and the congregating of employees.

Industrial Laundries

The majority of all work uniforms in use in American industry today are owned, cleaned, repaired and serviced by industrial laundries. Industrial laundries can relieve the sewage treatment plant superintendent of the problem of purchasing and maintaining the uniforms.

Each employee is individually measured for his own uniform. Several complete outfits are available for each employee. There is no capital outlay from sewage treatment plant funds, as the uniforms are owned by the laundry. Pick-up and delivery service is the same as for any commercial laundry. The entire operation is similar to that of towel and linen rental service.

Cost of this service is moderate, being only a weekly or monthly charge. It has attractions for both the large and small sewage treatment plant.

Conclusion

Attractive, neat work clothing, uniform in design and color, can aid materially in promoting employee morale and good public relations. The provision of clothing and adequate locker room facilities makes it possible for the employees to clean up after work and to leave the treatment plant presentably clothed in street clothing.

Just as nice clothing improves a woman's morale, it will help make a man proud of himself and his job.

TIPS AND QUIPS

Thinkers and Doers *

Two men sat down by a stream to eat their lunch. Not far away, a bridge had washed out where a footpath crossed the stream.

They noticed a blind man approaching the bridge from the other side. As he came near one of the men said, "If that blind man doesn't watch his step, he'll fall in." The blind man came closer. The other man said, "There sure is going to be an accident if that man keeps on walking." The blind man reached the edge of the stream and, splash, he fell in.

This little scene is enacted every day —a thousand times. Each day many people notice an unsafe condition or see an unsafe act committed, and do nothing about it. Personal injuries occur, not so much because the unsafe circumstances that lead up to eventual accidents are not recognized, but because no one takes the initiative to correct the circumstances.

Think and act for safety's sake!

* National Safety Council, *Associations News Letter*, April-May, 1956.

3½¢

At the current rate, the sewer rental fee of Philadelphia (Pa.) averages about $0.035 per day for the average family of four.

75-Year Guarantee

Long life has been a selling point for vitrified clay sewer pipe for many years. Recently the Clay Sewer Pipe Association, Columbus, Ohio, announced a guarantee on this pipe for three-quarters of a century. All clay pipe manufactured by Association members is now guaranteed against "impairment of service, injury, or failure which may be caused either by chemical decomposition or chemical disintegration." The original 50-year guarantee was adopted 25 years ago when clay pipe, installed a half-century before, was still giving good service.

Boise

To some readers of the Operator's Corner, Boise is the name of a city somewhere in the rocky reaches of Idaho. But to sewage treatment plant personnel in the Pacific Northwest and readers of "Sewage Gas," the newsletter from the Boise activated sludge treatment facilities, Boise holds a special place as a training ground for treatment plant operators and an academy for future supervisory personnel.

Since the initial operation of the Boise plant in 1950, nine operators have left to accept positions of increased responsibility and better pay. All except one have remained in the sewage treatment field; six are superintendents, one a foreman and another a building inspector. The ninth man has elected to continue his studies in sanitary engineering.

Paternal interest in these former employees is manifested each year by the publication of an "Alumni" issue of the plant newsletter, featuring articles by these men. The spirit of interest and encouragement in the profession, as displayed by the operating staff, transcends the pay scale and sends men on to take advantage of the need for operating personnel in the Pacific Northwest.

Other communities would do well to adopt a policy of offering encouragement to sewage treatment plant personnel!

Non-Skid Aluminum Tread Plate

Slip-proof features are combined with the corrosion resistance of aluminum in a non-skid abrasive aluminum tread plate. Manufactured by Alcoa, the plate is reported to provide sure footing even when covered with oil, grease or water. The non-skid feature is obtained from a fused aluminum abrasive oxide on one surface of the plate.

Third Philadelphia Plant in Operation

Philadelphia's Southeast Sewage Treatment Works is the last of the three plants to be placed in operation under an $80-million program begun in 1946.

Primary treatment is provided for a design flow of 136 m.g.d. and sludge is pumped 5 miles to the Southwest Works which was placed in service in December, 1954. The third plant is the Northwest Works, placed in operation in 1951. It is the remodeled and enlarged original treatment works constructed in 1912.

How to Pack a Stuffing Box *

1. Remove all old packing from stuffing box.

2. Clean box thoroughly, removing all accumulations.

* Johns-Manville, 22 E. 40th St., New York 16, N. Y.

3. Keep packing clean to prevent scoring of shaft or wall by grit or foreign matter.

4. Determine packing size by checking diameter of rod or shaft and inside diameter of stuffing box; thus making certain that the packing will fit and can compensate for shaft wear.

5. Never wind packing into a stuffing box. Use it in ring form only.

6. To make close fitting rings, cut the spiral or coil over a shaft or mandrel exactly the same size as the one on which the packing will be used. Use plain butt joints on braided packings.

7. To cut soft packing, apply a small piece of friction tape where it is to be cut. Remove tape before installing rings.

8. Install one ring at a time. Joints should be staggered and kept 90° apart. A tamping tool is helpful.

9. Another way to seat each ring is to place a taped split bushing over the shaft and, then, seat the ring with the gland follower.

10. After installing packing, take up bolts evenly so the gland follower is square on the rod.

11. Packing may bind if gland nuts are left too tight. Back them off until they are finger tight.

12. Allow packing to leak slightly when starting newly packed pump. Take up gland slowly as packing seats.

13. Provide means of lubricating rod and packing if possible.

14. If stuffing box has lantern, make sure it will be directly underneath the opening in the box when the packing is taken up.

15. Remove old packing when gland follower has compressed it to two-thirds the original volume. Then, it no longer lubricates and shaft may be scored.

Historic Milestone

Organization of the first permanent state health department in 1855 in Louisiana might well be considered the opening date in the era of modern health organization. The idea of state health organization spread rapidly, so that today all states have fully organized health departments.

Fire Prevention

Although summer weather is not compatible with thoughts of winter winds, the days slip from the calendar with a steady regularity. Now, while weather conditions permit, is a good time to check your plant facilities to prevent fire losses. The following timely suggestions are offered as a start:

Clean out debris.

Watch outside fires when burning brush or trash.

Clear out paint and oily rags accumulated from the painting season.

Check fuses, wiring and electrical equipment.

Store flammable liquids in safe containers and in a fireproof storage area, or out-of-doors.

Check stoves and heaters in preparation for the coming heating season. Be particularly attentive to portable heaters and their use.

Check pipes and chimneys.

Complete general repairs, now!

'56 Hatfield

The 1956 Hatfield Award competition closes September 1 for those 17 Member Associations eligible to name a recipient this year.

Federation Affairs

LOS ANGELES MEETING PLANS NEAR COMPLETION

The Hotel Statler, Los Angeles, California, will be the headquarters for the 29th Annual Meeting of the Federation of Sewage and Industrial Wastes Associations to be held October 8–11, 1956. This hotel, with attractive room and convention accommodations, will provide excellent facilities for the technical sessions, the manufacturers' exhibits, and enjoyment of the environment by all who attend. The convention setting in glamorous Los Angeles will make it desirable to combine attendance at the meetings with additional time for relaxation and sightseeing either before or after the meeting. Presentations on the industrial development and water problems of this section of the United States will furnish those in attendance with new ideas and additional technical information.

Many local members of the Host Association—the California Sewage and Industrial Wastes Association—have been at work on final details for the meeting, which promises to be one of the best in Federation history.

Local Committees

The Local Arrangements Committee, under the general chairmanship of Mr. Arthur G. Pickett, Industrial Wastes Engineer, Los Angeles County Sanitary District, San Marino, California, is composed of the chairmen of the following subcommittees:

Coordinating Committee: A. T. Wintersgill.
Registration Committee: N. F. Bravender.
Hotel Arrangements Committee: H. Harvey Hunt.
Finance Committee: A. A. Appel.
Entertainment Committee: K. A. Keirn.
Ladies' Entertainment Committee: F. L. Peirson and Sidney Preen.
Publicity Committee: J. C. McKee.
Local Host Committee: R. T. Antrim.
Inspection Trip Committee: R. D. Bargman and R. J. Barletta.

Early Registration

To help early arrivals avoid the Monday morning registration rush on October 8, the Registration Desk will be open in the second floor foyer of the Statler Hotel from 1 PM to 8 PM on Sunday, October 7. All who arrive during this period, or before, are urged to take advantage of this opportunity to register early.

Announcement to Membership

The formal announcement of the meeting was sent to all active and corporate members of the constituent associations of the Federation in July. That announcement contains further details as to technical and social programs, registration, manufacturers' exhibits, cost of the various functions, and a reservation card for hotel accommodations. Room reservations for hotel accommodations should be made directly with the headquarters hotel, Hotel Statler, 930 Wilshire Boulevard, Los Angeles 17, California. Anyone desiring additional copies of the formal convention announcement or hotel reservation cards may obtain them from the headquarters office of the Federation.

Among the interesting features of the meeting program are two special breakfast meetings, one for laboratory personnel and the other for those interested in sewer maintenance. Scheduled this year as part of the meeting program is a symposium on problems of state water pollution control programs. The research forum introduced last year will be featured this year as a symposium.

An inspection trip to the Hyperion sewage treatment plant has been scheduled, and special trips to local industrial waste treatment facilities will be arranged as interest warrants.

Finally, Southern California offers unexcelled opportunities for pre- or post-convention vacationing, including visits to Mexico and the Hawaiian Islands.

News and Notes

Of Persons and Activities in the Field of Hydrowastes

From Little Miami to Miami is the recent move of **David Backmeyer,** Superintendent of the Little Miami sewage treatment plant, Cincinnati, Ohio. He has accepted the position of Superintendent of the new high-rate activated sludge treatment facility at Miami, Fla. **C. F. Wertz** is Director of the Department of Water and Sewage, Miami.

A. E. "Bert" Berry, Secretary of the Canadian Member Association and the Canadian Section AWWA, has assumed another responsible position to add to his executive load as Director, Division of Sanitary Engineering, Ontario Department of Health. He is serving as General Manager and Chief Engineer of the recently created Ontario Water Resources Commission.

At the Dallas, Texas meeting, the American Society of Civil Engineers presented one of its first Research Awards to **Philip F. Morgan,** Sanitary Engineering Professor, University of Iowa, for his studies on accelerated sludge digestion.

New Jersey Director, **Sol Seid,** former Supervisor of Public Works, New Brunswick, has been appointed to the newly established post of Chief Engineer, Middlesex County, N. J. Sewerage Authority.

Eugene Weisberg, formerly a graduate student at Rutgers University, is now Research Associate in the Graduate School of Public Health, University of Pittsburgh.

Karl R. Kennison (70), member of the New England Member Association, has retired as Chief Engineer, New York City Water Board, in order to devote more time to his personal interests.

Vice-President John Cunningham is recuperating nicely following an operation in recent months. However, his travel and activities may be restricted for sometime.

Wayne A. Kivell has joined the sanitary engineering staff of Gibbs & Hall, Inc., N. Y., following retirement after 33 years as sales engineer with the Dorr-Oliver Co.

Professor **F. W. Gilcreas,** University of Florida, spent several months in the Far East (Tokyo, Seoul, Taipeh, Macao, Hong Kong and Manila) as a consultant to WHO on the establishment of international standards of water quality.

B-I-F Industries, Inc., has announced the promotion of **John R. Hartley** to the position of General Manager of the Builders-Providence, Inc., Division. He has been Vice-President and Manager of Project Sales since 1949.

Kenneth S. Watson, Consultant for the General Electric Co. on water management and waste control, has recently returned from Geneva, Switzerland, where he served as Engineer Advisor to the U. S. Delegation to the 9th Meeting of the World Health Assembly. He is the first representative from industry to be chosen for this position.

The ranks of the consulting engineers were strengthened when **James H. Stephens,** former Chief Sanitary Engineer, South Carolina State Board of Health, joined The Harwood Beebe Co., Spartanburg, S. C.

Pomeroy and Associates announce the affiliation with their firm of **Carl B. Johnston,** formerly a staff engineer, Los Angeles Regional Water Pollution Control Board.

Kaarlo Nasi, USPHS, has recently been assigned as Chief, Emergency Sanitation Division, Health Office, Federal Civil Defense Administration, Battle Creek, Mich. Prior to this assignment, he was Assistant Chief, Water Supply and Water Pollution Control Branch, USPHS, Washington, D. C.

W-K-M Manufacturing Co. has moved into a new $15 million home in Houston, Texas. This well-known manufacturer of valves was acquired by ACF Industries, Inc., in April, 1954.

The Hawaiian Islands are due for a post-convention visit by several Federation members, including **President George Martin** and **Past-President Art Niles.**

Reviews and Abstracts*

Continuous Measurement of Dissolved Oxygen in Water. By H. S. Levine, W. V. Warren, E. C. Tsivoglow, and W. W. Walker. *Anal. Chem.*, **28**, 343 (1956).

The authors have developed an intriguing device for the continuous indication or recording of the dissolved oxygen level in water. The measurement can be calibrated in per cent of saturation between zero and 150 per cent.

The sensing element may be defined as a volume of gas in equilibrium with the water which is pumped through the element continuously. The gas is recirculated and mixed with the water sample as the water sucks the gas into a gravity aspirator. The change in composition of the gas as controlled by its contact with the sample is analyzed for its oxygen content by a thermo-conductivity unit. There is a source of oxygen to make up the gas volume as the sample reduces the pressure from dissolving the oxygen.

The dissolved oxygen is indicated by composition of the gas after contact with the water.

A complete theoretical discussion of the sensing element is given. R. S. Ingols

New Colorimetric Method of Determination of Dissolved Oxygen in Water. By R. L. Babkin. *Elek. Stansii*, **25**, 16 (1954).

Dissolved oxygen may be determined in concentrations from 0.02 to 0.5 p.p.m. by reaction with leucoindigo carmine to form indigo carmine, the intense blue color of which is measured photometrically.

500 mg. of finely ground indigo carmine is placed in a small beaker and mixed with 5 ml. concentrated H_2SO_4, heated on a water bath until dissolved, then diluted with water to 1 l. and standardized by titration with 0.01 N. $KMnO_4$. The oxygen titer should be .02 to .03 mg. per milliliter.

To a measured volume of the acid solution, 10 per cent NH_3 is added to give a final NH_3 concentration of 0.2 N. The ammoniacal solution, which is not stable more than 24 hr., is reduced as needed by adding it to a buret one-half full of zinc amalgam. The reduction is reported to be rapid, and the solution is ready for use when the blue color of the indigo carmine changes to the yellow of the leuco base. (Abstractor's note: Mixing may be necessary.)

The water to be tested is collected in a completely filled, stoppered bottle. The required volume of leucoindigo carmine, calculated as shown, is added, the sample is mixed and the color is compared with standards.

The standards consist of dilutions of the acid indigo carmine solution, containing picric acid to approximate the yellow color of the unreacted leuco compound. New standards must be prepared weekly. The volume of indigo carmine for each standard is:

$$V_i = \frac{CW}{1{,}000\ T}$$

where

C is the oxygen concentration represented by the standard;
W is the final volume of the standard;
T is the titer of the indigo carmine in milligrams of oxygen per milliliter.

A stock solution of picric acid containing 370 mg. per liter is prepared. The volume of this solution to be added to each standard is:

$$V_p = \left[\frac{(C_m - C)\ W}{1{,}000}\right]\left[\frac{1}{.02} + \frac{1}{T}\right]$$

where

C_m is the oxygen concentration represented by the highest standard of the series,

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N. W., Washington 16, D. C.

0.02 is the weight of oxygen (mg.) equivalent to 1 ml. of the picric acid solution.

The other symbols have the same significance as in the previous equation.

The volume of color reagent to be added to each sample to be tested is then:

$$V = \frac{C_m W}{1{,}000\ T}$$

where W now represents the sample volume in milliliters.

The method is reported to be suitable at any pH below 10, and to be unaffected by temperature, nitrates, nitrites, sulfates, chlorides, phenol, iron, zinc and ammonia, and small concentrations of sulfite. In the presence of sulfite, the color slowly fades, but the accuracy is unaffected if the colors are read within one hour after development.

Copper interferes, but its effect is eliminated by adding 1 gm. of seignette salt (sodium potassium tartrate) to each 100 ml. of the ammoniacal indigo carmine solution. M. C. RAND

Some Hydraulic Aspects of Sewerage and Sewage Disposal. By C. B. TOWNSEND AND G. W. WILKINSON. *Proc. Inst. Civil Eng.* (Brit.), **4**, Part III, 662 (1955).

The efficient operation of sewerage systems and treatment plant depends on a sound application of a great variety of hydraulic principles to ensure both the effective transport of solid particles and their separation from the liquid stream at various stages in the treatment process. Certain aspects of these operations are considered and representative examples of those aspects of the subject in which the engineering design would greatly benefit from the assistance of the specialist in hydraulics are discussed. The need for further research in this field is again emphasized since less progress than might have been hoped for has, in fact, been achieved.

Additional topics discussed are storm water runoff, sewer discharge formulae and the corresponding formulae for channels and pipes, the special hydraulic problems of handling sewage, and particular appurtenances such as sewer junctions, backdrop manholes and spillways. The discussion includes sewage-treatment problems, in particular the control of velocities and levels, the distribution of flow and the sedimentation processes.

PETER C. G. ISAAC

Dewatering of Sewage Sludges by Vacuum Filtration. By B. R. S. JONES AND S. H. JENKINS. *Surveyor*, **114**, 923 (1955).

A condensation of the report of experimental work performed at the Yardley Sewage Works, Birmingham, Eng. Mention is made of a method of determining the "specific resistance" of sludges to vacuum or pressure filtration. Use of this parameter then permits good prediction of plant-scale results from small-scale experiments. Details of the method, however, are not presented.

With raw sludge, lime was the most effective of a number of coagulants tested. Yields up to 4 lb. of dry solids per square foot of filter per hour were realized with 10 per cent addition of lime to the sludge. Digested sludge filtered poorly and had a high coagulant demand. After elutriation, results were improved, but were still inferior to those obtained with the raw sludge. M. C. RAND

Sewage Disposal in a Rural District. By J. S. HOPKINS. *Jour. Inst. Munic. Eng.* (Brit.), **81**, 452 (1955).

The current methods and need for future development of rural sewage disposal are presented. The tasks of such schemes are numerous but never large and this requires careful planning of maintenance work.

Meriden R.D.C. is typical of a rural sewage disposal area. It has a population of 40,000 served by 21 disposal plants. Pail closet collection is the principle problem, since there are 1,200 in the area, including schools, factories and similar places. Two vehicles are used to achieve a general weekly service, but labor and other difficulties often make this impossible. The only solution is a change over to waterborne systems. To promote this, grants of up to 50 per cent of the conversion cost are made by the local authority. Difficulty is also experienced in disposal of the collected waste; at present most of the sludge is lagooned.

Cesspool emptying is another essential service. This is handled by three vehicles at a subsidized rate of 7/6d. per hour. Residents are encouraged to make use of

the service which is operated by refuse collection crews. Full details of the control and accounting of the system are given. The four large sewage disposal works have permanent attendants, the remainder are visited by a mobile crew of three men with a full complement of equipment. Desludging is carried out by the cesspool machines. A. WHETTON

Taunton Sewerage and Sewage Disposal. By A. H. S. WATERS. *Jour. Royal Soc. Health*, 75, 816 (1955).

After a brief historical survey of sewage treatment with particular reference to the Taunton works, the drainage problems involved and the solutions adopted are described. Like many towns in Britain which have had main sewerage for more than half a century, Taunton with a population of 36,000 has grown by spreading outwards from the center; as a result the sewers have been extended piecemeal and are now generally heavily overloaded. The sewers are in a poor state of repair so that infiltration is high. Dry-weather flow is about 2.45 m.g.d. (Imp.) although the combined sewers carry peak flows of 40 m.g.d. The Town Council has decided, however, that the replacement of the existing treatment works is the most urgent need. The existing sewers will be used, intercepted at the old works, and three miles of interceptors will be constructed to the new works. Approximately one mile east of the old works is the storm-water overflow to the River Tone.

The new sewage treatment works has been designed for a dry weather flow (d.w.f.) of 2.75 m.g.d. and, as is standard practice in Britain, will treat up to 3 times the d.w.f. The design, however, is unusual in that the effluent will be recirculated when the flow is less than 3 times the d.w.f. to bring it up to this amount. The plant consists of rough screens, comminutors and grit channels followed by a storm-water overflow controlled by a venturi flume, which by-passes to storm water settling tanks all flows over 3 times the d.w.f. The flow then passes through one of three horizontal-flow sedimentation tanks and after make up, if necessary, to 3 times the d.w.f., through 16 biological filters (at the rate of 100 gal. cubic foot per day), and 8 final settling basins.

Sludge from the settling tanks and storm water tanks is digested and dried on open beds; digester gas is used for heating the digesting sludge in an external heater. Drainage from the drying beds and sludge from the final tanks is returned to the influent. Scheduled for completion in 1957, the cost will be approximately $2,000,000.

PETER C. G. ISAAC

Clarification, Sedimentation, and Thickening Equipment—A Patent Review. By W. L. BARHAM, J. L. MATHERNE AND A. G. KELLER. Bull. No. 54, Eng. Exp. Station, Louisiana State University, Baton Rouge, La. (1956).

This is a review of various types of primary and auxiliary devices which have been proposed and developed over the past 106 years for the separation of finely divided suspensions into relatively clear overflow and thickened underflow. The three phases of flocculating, settling, and thickening as carried out in clarifiers, settling tanks, separators and thickening vessels are covered in an extensive survey of patent examinations. A historical background is presented and 176 patents, pertinent to the subject, are illustrated and briefly described in the order of the date of issuance. A reference index of 360 patents is presented in the form of a bibliography.

HOWARD B. BROWN

Report of the Rivers Department, City of Manchester (Great Britain), for Year Ended March 31, 1955.

This report by the Rivers Committee marks the resumption of an annual report on the work of the Department, which includes the City of Manchester, Mersey River Board, Manchester Ship Canal and Upper Mersey Navigation Commission.

During the year the Rivers Committee recommended a scheme for the reconstruction and extension of the sewage treatment works at Davyhulme. Some 35 acres of contact beds were cleaned and returned to service, with slight improvement in purification. The three activated sludge systems treated about one-third the sewage flow, although the diffused air system has produced a satisfactory effluent only occasionally, removing about 79 per cent of the B.O.D. of the settled sewage. The adjustments of the new "high intensity" cones in the Simplex plant were completed in May, 1954, resulting in an effluent superior to the

bio-aeration (Sheffield) unit and the diffused air unit, with less power and a shorter period of aeration. Diffused air units have been converted to Dome type diffusers. An excessive amount of foam occurred in the diffused air units, which is to be suppressed by water spraying.

Recruitment and retention of labor (some 104 persons) continues to be a major problem at Davyhulme. The mechanical cleaning of settling tanks is being arranged.

During the year, the sludge vessel made 181 trips and handled 217,200 wet tons of sludge. The cost of sludge disposal for the year, including loan charges, was approximately $1.00 per wet ton. The average flow at the Davyhulme Works is 69,748,000 g.p.d. (Imp.) from a population of 834,000, or 84 g.p.d. (Imp.) per capita.

Averaged Analyses, Davyhulme Works

Determination (p.p.m.)	Raw	Effluent	
		Sedimentation	Contact
Nitrogen:			
Ammonium	24.8	25.5	23.6
Albuminod	6.6	4.55	3.99
Cl. as chlorides	367	357	354
Oxygen absorbed*	114.4	86.9	74.4
B. O. D.	223.7	167.1	—
Susp. solids	226	69.0	64.0

* From N/80 permanganate in 4 hr. at 26.7C°.

The average results of operation of the activated sludge plants at Davyhulme for the year was as follows:

The average quality of "Simplex" effluent was better than last year, with a lower required h.p. Less foaming was noted.

The effluent of the entire Davyhulme Works averaged:

Nitrogen, ammonia (p.p.m.)	24.1
B. O. D. (p.p.m.)	79.4
Susp. solids (p.p.m.)	50.0
B. O. D. reduction (%)	65

LANGDON PEARSE

A Process for the Treatment of Effluents from Carbonisation Plants. By R. J. BARRITT, D. E. CUNNINGWORTH, AND E. R. FORLIN. *Jour. Inst. San. Eng.* (Brit.), **54**, Part III, 169 (1955).

This paper relates to effluents from coke ovens, chiefly from British practice. Three methods of recovery of ammonia are described, direct, semi-direct and indirect. An analysis of a spent liquor from an indirect plant is given.

The polluting effects may be manifest in high oxygen demand, toxicity, odors and taste. Phenols in drinking water occasion obnoxious tastes and odors. Possible methods of treatment are described in detail. Work in South Wales is described where the biological process is considered satisfactory.

The disposal of liquor by passing it through a washery is advantageous. Experiments on biological oxidation are outlined. In conditioning the waste liquor, soil bacteria were found helpful.

A comprehensive list of reference is supplied, and discussions by several members.

LANGDON PEARSE

Operating Results, Davyhulme, Eng., Year Ended March 31, 1955

Data	Bio-Aeration Plant	Simplex Plant	Diffused Air Plant—Units		
			1	2	3 to 7
Flow (m.g.d. [Imp.])	0.859	2.17	3.14	2.83	12.14
Period (hr.)	12.9	7.4	10.5	11.5	10.6
H. P. per mg.	25.0	24.3	37.3	40.6	37.9
Effluent determinations:					
Nitrogen, ammonia (p.p.m.)	23.9	23.2	23.7	23.6	23.6
B. O. D. (p.p.m.)	25.8	19.7	24.8	33.9	35.5
Susp. solids (p.p.m.)	24.0	23.0	24.0	29.0	31.0
B. O. D. reduction (%):					
Sewage	88.5	91.2	88.9	84.8	84.1
Settled sewage	84.6	88.2	85.2	79.7	78.8

The Treatment of Gaseous and Liquid Effluents Attendant in the Manufacture of Viscose Cellulose Film. By C. R. Roberts and H. T. Farrar. *Jour. Royal Soc. Health*, **76**, 36 (1956).

In this interesting paper the authors describe the development of a liquid scrubbing process for the sulphur fumes from the regenerating bath and casting machine in the manufacture of viscose film at Bridge Hall Mills, Bury, Lancashire. In a week some 40,000 tons of gas are scrubbed, the concentration of hydrogen sulphide being reduced from 250 to 5 p.p.m. Early efforts at scrubbing consisted simply in spraying water on the fan blades; then chlorinated water was used but the resulting nuisance was even more objectionable. The first effective results were obtained with the "Manchester" process; in this a liquid medium was used in vertical steel towers. The liquid contains ferric oxide as an oxygen-carrier, the oxide being prepared by blowing air into a solution of ferrous sulfate and sodium carbonate. In the latest installation, a horizontal brick scrubber is used, lined with asphalt and roofed with steel. The scrubber is 90 ft. long by 8 ft. square and consists of three chambers, with exhaust fans in tandem. In the first chamber the hydrogen sulfide is removed by a modification of the "Manchester" process, in the second a spray of caustic-soda solution removes traces of the sulfide, and in the third a water spray removes entrained caustic-soda mist.

The noxious liquid effluent from the gas scrubbers joins the acid waste from the regeneration baths. The liquid effluent, after treatment, is discharged to the River Roche. This effluent amounts to 300 g.p.m. (Imp.), with an acidity of decinormal sulfuric acid, and is neutralized by a batch process with precipitated calcium carbonate (a waste product from the soda-lime process for the manufacture of caustic soda). The sludge is, at present, discharged with the effluent.

Peter C. G. Isaac

Corrosion Resistant Materials in Plumbing and Drainage for Chemical Wastes. By R. T. Gillett. *Jour. Inst. San. Eng.* (Brit.), 235, **54**, Part III, 202 (1955).

This paper considers various problems in handling corrosive liquids, discusses suitable materials for pipework, including copper, lead, stainless steel, cast iron, ceramics and plastics. Jointing materials are commented upon. A brief bibliography and discussion follows.

Langdon Pearse

Sanitary Engineering in Alaska. By C. I. Sterling. *Jour. Boston Soc. Civil Eng.*, **42**, 4, 345 (Oct., 1955).

The author describes briefly the geography and the climate. Temperature ranges from $-56°$ to $+60°$ F., with an annual rainfall varying from 5 to 151 in., according to locality. In 1950 the census population was 128,643. While sanitation needs are apparent, the effect on health is difficult to appraise statistically. Enteric diseases are common.

Only six of the 34 water systems serving a population of more than 100 persons are satisfactory. The only water filtration plant is at Fairbanks, primarily for iron removal. Eighteen other supplies are chlorinated.

Only fifteen communities have sewerage systems, and there are no sewage treatment plants. Industrial wastes are a problem, particularly from fish canneries and paper pulp mills.

Governmental aid has been authorized for water supply and sewerage. However, there are only 28 incorporated municipalities in Alaska and needed aid cannot be extended to many unincorporated communities, which lack the financial ability to underwrite their portion of the loan.

The problem of housing, water supply, sewage, and waste disposal is particularly critical in the low temperature areas known as the permafrost region, which makes up about 60 per cent of the total area of the territory, or 170,000 sq. mi.

The author commends the research work being conducted on the various Alaskan problems, and lists eight projects for future study. Tabular data on water supply and a bibliography are appended.

Langdon Pearse

The Design of Sewerage and Sewage Disposal Works. By E. D. Grubb. *Jour. Inst. Munic. Eng.* (Brit.), **82**, 102 (1955).

This essay briefly describes the standard methods of sewage disposal.

P. Coackley

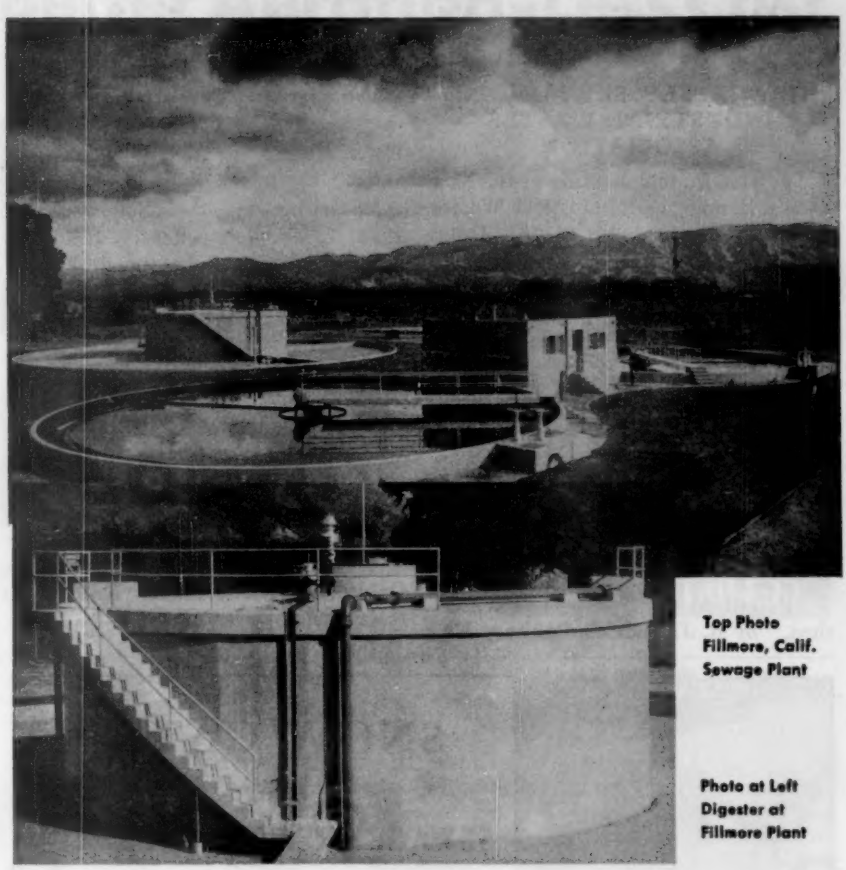

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Photo at Left
Digester at
Fillmore Plant

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The 41st Annual Meeting of the New Jersey Sewage and Industrial Wastes Association was held at the Hotel Traymore, Atlantic City, N. J., March 14–16, 1956. Approximately 392 members and guests were registered.

The technical sessions were moderated by Andrew Palmer, Superintendent of the Plainfield, North Plainfield and Dunellen Joint Meeting Sewage Disposal Plant; John Collom, Superintendent of Sewage Treatment Plant, Bordentown; and John Hood, Superintendent, Sewage Treatment Plant, Ridgewood.

The following papers were given:

"Pollution Control on a Watershed," by R. J. Budrick, Sanitary Engineer, Jersey City Water Works.

"Long Distance Sludge Pumping in Force Mains," by E. T. Killam, Consulting Engineer, Short Hills.

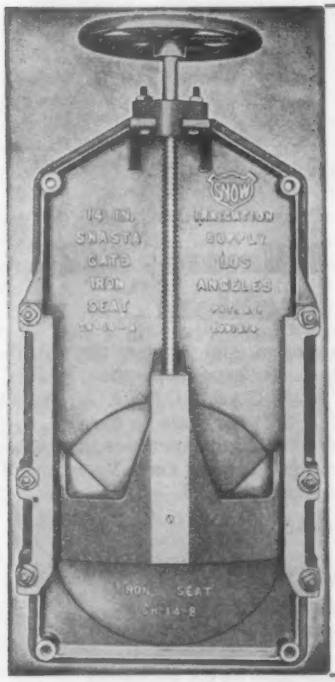
"Starting up the New Camden Plant," by John Frazee, Superintendent, Sewage Treatment Plant, Camden.

"Additions to the Morristown Plant," by G. E. Burke, Superintendent, Sewage Treatment Plant, Morristown.

"Grit Removal in Small Plants," by C. S. Olsen, Dorr-Oliver, Inc., Stamford, Conn.

"Control of Calcium Sulfate Supersaturation During Lime Neutralization," by W. A. Parsons and H. E. Orford, Rutgers University.

(*Continued on page 322a*)



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"The Assimilation Behavior of Certain Toxic Organic Compounds in Natural Waters," by A. B. Cherry, Sanitary Engineer, A. J. Gabaccia, Supervising Engineer, and H. W. Senn, Chemist, Industrial Wastes Treatment, Lederle Laboratories Division, American Cyanamid Co.

"Waste Treatment at the Ford Motor Company Plant at Mahwah, New Jersey," by E. R. Grich, Ford Motor Company, and President, Edward R. Grich, Inc.

"Carter-Edco Sludge Concentrator," by Edmund Smith, Ralph B. Carter Co., Hackensack.

"Problems of Combined Water and Sewage Rentals," by Val Edwards, Commissioner of Public Works, Bridgeton."

"Sewerage Financing" by A. F. Haiback, Municipal Bond Analyst, B. J. Van Ingen & Co., Inc., N. Y.

"Program of the New Jersey State Department of Health for Solid Wastes Disposal," by Robert S. Shaw, and John Zemlansky, New Jersey State Department of Health.

"Application of the Catalytic Reduction Process," by T. H. Forrest, Chicago Pump Co., Chicago, Ill.

At the Operators' Breakfast a symposium on digester control was moderated by Louis J. Fontenelli, Supervising Engineer, Rahway Valley Sewerage Authority.

The Arthur Sidney Bedell Award was presented to Henry Van Der Vliet, Superintendent, Joint Meeting, Rutherford, East Rutherford and Carlsbad, by David B. Lee, immediate Past-President of the Federation.

At the business meeting excellent reports were received from the various committees, including in particular the Legislative Committee, the Arrangements Committee for the 1955 Annual Meeting of the Federation, and the Nominating Committee.

The following officers were elected:

President: John Collom, Bordentown.
1st Vice-President: Andrew Palmer, Dunellen.
2nd Vice-President: Robert J. Budrick, Boonton.
Secretary-Treasurer: M. S. Kachorsky, Manville.

M. S. KACHORSKY,
Secretary-Treasurer

LOUISIANA CONFERENCE ON WATER SUPPLY AND SEWERAGE

The 1956 Annual Meeting of the Louisiana Conference on Water Supply and Sewerage was held in conjunction with the 19th Annual Short Course for Superintendents and Operators of Water and Sewerage Systems at Louisiana State University, Baton Rouge, La., March 14–16, 1956. Total registration for the meeting and short course was 142.

Among the papers of interest to sewage works personnel were the following:

(*Continued on page 325a*)

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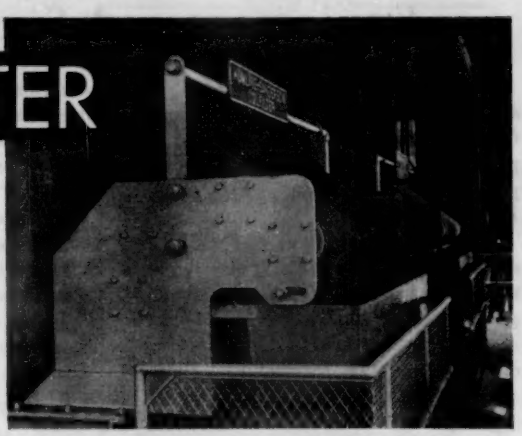

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Central Plant: Design Conditions; Population 60,000. Average Daily Flow 5.15 MGD. Maximum Daily Flow 10 MGD. Two 100 Sq. Ft. COILFILTERS.

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Chempumps—New Model S series seal-less centrifugal pumps for special or corrosive liquids service feature improvements and lower costs.—Chempump Corp., 1300 East Mermaid Lane, Philadelphia 18, Pa.

Pneumatic Control—A compact, easily installed and serviced pneumatic control unit for liquid flow and pressure control systems is described in Bulletin 285–M30.—Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.

Strip-Chart Recorders—New bulletin describes 6-in. strip-chart recorders for recording pressure, liquid level, temperature, flow and mechanical motion.—Bristol Co., Waterbury 20, Conn.

Industrial Rubber Products—Illustrated bulletin describes industrial rubber products. Included are hoses, belts, lining and friction materials.—Thermoid Co., Trenton, N. J.

Turbo-Blowers—Bulletin No. 142–B presents data on turbo-blowers in sizes up to 250 h.p. for all types of aeration jobs.—Spencer Turbine Co., Hartford, Conn.

Valves—Bulletin 5403 describes gate, check and other valve products for water works which find application in sewage works.—Darling Valve & Manufacturing Co., Williamsport, Pa.

Instrumentation Index — Bulletin 100–D is an index of instrumentation literature by subject, industry and product. It covers catalogs, bulletins, specification sheets, data sheets and articles. If you have M–H instruments you will want this index.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

Sewer Lining—A continuous plastic sewer lining, T-Lock Amer-Plate, is described in a new brochure. The back of the polymer vinyl resin sheets have T-shaped ribs which assure mechanical locking of liner to the concrete sewer pipe when the pipe is poured.—Amercoat Corp., 4809 Firestone Blvd., South Gate, Calif.

Butterfly Valves — Tight-closing, rubber-seated butterfly valves are the subject of Bulletin 650–L1B.—Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.

Dust Collectors—Elimination of waste and more effective operating conditions by the control of dust are the subjects of Bulletin 70–G1.—Omega Machine Co., 345 Harris Ave., Providence, R. I.

Digester Sludge Heater—Application, construction and operation of the *HeatX* digester sludge heater are described in the 20-page Bulletin No. 24S82.—Walker Process Equipment Co., 840 N. Russell St., Aurora, Ill.

Flow Meters—Bulletin No. 806 gives detailed data on new small-size receivers and draft, pressure and temperature gauges. The new gauges are reported to give excellent readability and accuracy with a scale measuring only 5 in. high. Gauges read all standard draft ranges and may be mounted singly or in groups.—Republic Flow Meters Co., 2240 Diversey Parkway, Chicago 47, Ill.

Pressure Operated Pump Control—Bulletin RS–3 describes an improved pressure operated pump control featuring synchronous motor-type time delay and a purged air system for operating one or more pumps.—Healy-Ruff Co., 2255 University Ave., St. Paul 14, Minn.

Aluminum Pipe— New 18-page booklet presents complete data on the use of aluminum pipe and fittings.—Aluminum Company of America, 770 Alcoa Bldg., Pittsburgh 19, Pa.

Diaphragm Chemical Pumps—Bulletin 1201 describes heavy duty, multipurpose pump for feeding chemical solutions.—B–I–F Industries, Inc., 345 Harris Ave., Providence, R. I.

"Safety Practices," by G. I. Cambre, Associate Professor of Mechanical Engineering, Louisiana State University.

"Cross Connections and Back Siphonage," by F. W. McDonald, Associate Professor of Civil Engineering, Tulane University.

"Individual Waste Disposal Facilities," by C. E. Bishop, Regional Engineer, Louisiana State Health Dept.

"Fundamentals of Sewage Treatment," by Thomas M. Love, Professor of Hydraulic Engineering, Louisiana State University.

"Operation of Primary Treatment Facilities," by Ben S. Graves, Jr., Supervisor of Waste Disposal, Shell Oil Company, Norco.

"Operation of Secondard Treatment Facilities," by William Hood, Public Health Engineer, Louisiana State Health Department.

"Sewage Treatment Plant Control Tests," by J. B. Baudoin and J. E. Nugent, Chief Operator and Chemist, respectively, Sewage Treatment Plant, Lafayette.

"Sewage Oxidation Ponds," by James F. Coerver, Regional Engineer, Louisiana State Department of Health.

"Preventive Maintenance of Pumps and other Equipment," by George F. Matthes, Professor of Mechanical Engineering, Louisiana State University.

A round table discussion of sewerage problems was also a feature of the conference.

At the annual conference banquet, George W. Martin, Federation President, represented the Federation.

Officers elected were:

Chairman: Leo Bankston, Baton Rouge.

Vice-Chairman: A. A. Hirsch, Shreveport.

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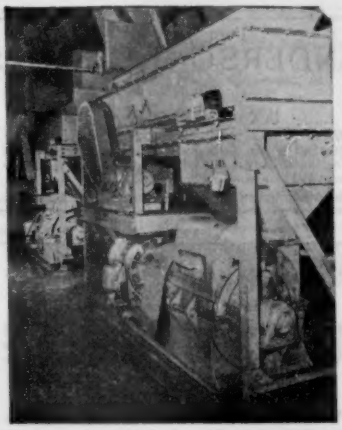

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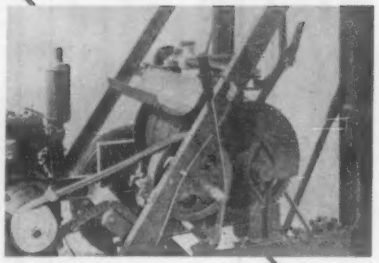

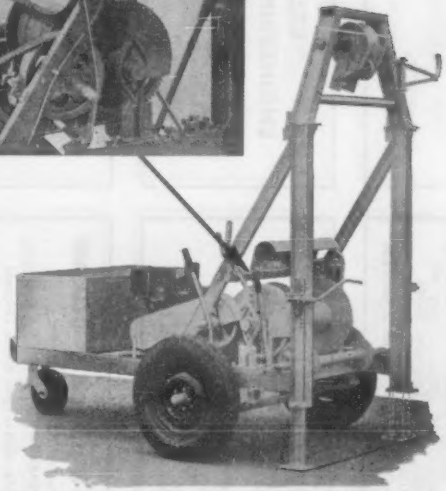

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